Troubleshooting Precast Production

Presented by: Mel C. Marshall
Mel C. Marshall Industrial Consultants Inc.
(604) 943-8512
mel@mcmconsultants.ca
www.precastconcretebc.com

“...water and concrete are the two materials most used by mankind: water in the first place and concrete in the second.”

ACI Honorary Member Adam Neville – December, 2000 issue of Concrete International

Concrete

- Inexpensive/competitive
- Simple Technology
- Readily Available
- Mold to any shape
- High Strength
- Durable
- Environmentally friendly

The bitterness of poor quality remains long after the sweetness of low price is gone

(Unknown)
What's Important?

- Aggregates – FM, absorption, gradation, clean, etc.
- Powder – cements, SCMs
- Water – moisture control, how to determine absorption, etc.
- Mix Designs – how SG affects volumes, causes of over/under yielding, etc.
- Air Content – good and bad air
- SCC – potential problems, required tests, etc.
- Reinforcing – importance of spacing, location, etc. and types
- Consolidation – how to size and locate vibrators, using stingers correctly
- Curing – why it is important to control temperature, eg. DEF, etc.
- Certificates – the importance of having and understanding mill certs
- NPCA Certification – what is required, and why
- Anything else you want to discuss

Excellent Reference Books

- Properties of Concrete by Dr. A. M. (Adam) Neville
- Self-Compacting Concrete by De Shutter, Bartos, Domone, Gibbs
- Design and Control of Concrete Mixes - PCA

Aggregate Specifications

- ASTM C33 - Normal Weight Aggregates – be familiar with the required tests
- ASTM C330 - Lightweight Aggregates
- ASTM C637 - Radiation Shielding Aggregates
  (Heavyweight – Hematite, steel shot, steel shavings)

Aggregate Size

- Maximum Size:
  – The smallest sieve opening through which the entire amount of aggregate is required to pass.
- Nominal Maximum Size:
  – The smallest sieve opening through which the entire amount of aggregate is permitted to pass.
- Example: ASTM C33 requires that 100% of a # 67 coarse aggregate MUST pass the 1” sieve but 90 - 100% MAY pass the 3/4” sieve, therefore # 67 aggregate is considered to have a Maximum size of 1” and an Nominal Maximum size of 3/4”,

Larger Aggregate Test

• Check for silt or clay
• Mason jar test is not official test, but only an indication of how much fine material is present.
• Check ASTM C33 and FDOT Sections 901 and 902 for amount and type of allowable fine material.
• Use a “Mason jar”
Gradation
- Distribution of particle sizes
- Grading is determined by ASTM C 136
- Well graded concrete aggregates will result in fewer voids between particles = less cement paste demand

Aggregate Gradation Effects
- Workability
- Pumpability
- Economy
- Porosity
- Shrinkage
- Durability

Aggregate Gradation (Sand)
- Also known as “sieve analysis”
- It is the distribution of particle sizes
- “Well-graded” aggregates:
  - particles evenly distributed between fine and coarse
  - require less cement and water than “poorly graded” aggregates
  - Careful choice of aggregates provides for optimization of cement, water and admixtures

Sieve Size
- Size of the screen opening  OR
- The number of openings per lineal inch. For example, #100 sieve has 100 x 100 openings in each square inch (i.e. 100 in each direction)

Most Common Sieve Series

<table>
<thead>
<tr>
<th>Sieve Size (inch)</th>
<th>Metric Size (mm)</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2”</td>
<td>38 mm</td>
<td>37.5 mm</td>
</tr>
<tr>
<td>1”</td>
<td>25 mm</td>
<td></td>
</tr>
<tr>
<td>3/4”</td>
<td>20 mm</td>
<td>19 mm</td>
</tr>
<tr>
<td>1/2”</td>
<td>12.5 mm</td>
<td></td>
</tr>
<tr>
<td>3/8”</td>
<td>10 mm</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>#4</td>
<td>4.75 mm</td>
<td>4.75 mm</td>
</tr>
<tr>
<td>#8</td>
<td>2.50 mm</td>
<td>2.36 mm</td>
</tr>
<tr>
<td>#16</td>
<td>1.12 mm</td>
<td>1.10 mm</td>
</tr>
<tr>
<td>#30</td>
<td>0.6 mm</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>#50</td>
<td>0.3 mm</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>#100</td>
<td>0.15 mm</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>#200</td>
<td>0.075 mm</td>
<td>0.075 mm</td>
</tr>
</tbody>
</table>

Effect of Gradation
(Approximate mix proportions)
- 33% of 3/8”, #4 – provide strength
- 33% of #8, #16 – fill the voids
- 33% of #16, #30, #50 – for finish
Gradation for Leaking Manholes

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Weight (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>½”</td>
<td>7</td>
</tr>
<tr>
<td>3/8”</td>
<td>163</td>
</tr>
<tr>
<td>#4</td>
<td>1356</td>
</tr>
<tr>
<td>#8</td>
<td>396</td>
</tr>
<tr>
<td>#16</td>
<td>115</td>
</tr>
<tr>
<td>#30</td>
<td>221</td>
</tr>
<tr>
<td>#40</td>
<td>374</td>
</tr>
<tr>
<td>#50</td>
<td>348</td>
</tr>
<tr>
<td>#100</td>
<td>173</td>
</tr>
<tr>
<td>#200</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>3155</td>
</tr>
</tbody>
</table>

¼” and #16 is 16.2% #8 and #16 is 48.4% #30 through #200 is 35.4%

Aggregate Size Effects:

* As the maximum size aggregate increases, the amount of paste needed for a given slump decreases.
* The maximum aggregate size used in a concrete mix is dictated by the size of the structural member and the spacing between reinforcing steel.

Fineness Modulus (FM)

- A single number system used to express the fineness or coarseness of an aggregate
- Higher values indicate coarser grading
- Sum of cumulative % retained on the standard sieves
- Certain sieves are NOT counted (even if used)
- Standard Sieves: 38 mm (1-1/2”), 20 mm (3/4”), 10 mm (3/8”), 4.75 mm (#4), 2.50 mm (#8), 1.12 mm (#16), 0.6 mm (#30), 0.3 mm (#50), 0.15 mm (#100).
- C33 specifies that FM of sand be between 2.3 and 3.1
- Can be helpful in calculating blends of two materials
- FM of coarse aggregate can also be calculated and can aid in blending coarse and medium size materials

Fineness Modulus of Sand

- The fineness modulus is calculated from the particle size distribution of the fine aggregate
- Values for sand suitable for concrete should range between 2.3 and 3.1
- Values can’t differ by more than 0.2
- Coarse sand has a higher FM than fine sand
- The FM influences the bulk volume of coarse aggregate
### Gradation & Fineness Modulus:

<table>
<thead>
<tr>
<th>Sieve Size, (mm)</th>
<th>Sieve Size, (US)</th>
<th>Mass, (g)</th>
<th>Ind. % Retained</th>
<th>Cum % Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>1 1/2&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>75</td>
<td>1&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>37.5</td>
<td>3/4&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>1/2&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9.5</td>
<td>3/8&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.75</td>
<td># 4</td>
<td>25</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>2.36</td>
<td># 8</td>
<td>163</td>
<td>12.9</td>
<td>14.9</td>
</tr>
<tr>
<td>1.18</td>
<td>#16</td>
<td>228</td>
<td>18.0</td>
<td>32.9</td>
</tr>
<tr>
<td>0.6</td>
<td># 30</td>
<td>278</td>
<td>22.0</td>
<td>54.9</td>
</tr>
<tr>
<td>0.3</td>
<td># 50</td>
<td>355</td>
<td>28.1</td>
<td>83.0</td>
</tr>
<tr>
<td>0.15</td>
<td># 100</td>
<td>177</td>
<td>14.0</td>
<td>97.0</td>
</tr>
<tr>
<td>Pan</td>
<td>Pan</td>
<td>38</td>
<td>3.0</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1264</td>
<td>100</td>
<td>2.85 FM</td>
</tr>
</tbody>
</table>

**Sieve Loss Check**: 0.24%

### Why Are Aggregates Critical to the Water Content of Concrete?

- Aggregates take up the largest amount of volume in concrete.
- Aggregate particle size, distribution, shape, and texture affect the amount of water needed in concrete.
- Therefore, more than any other material, aggregates have the greatest affect on the water needed for a given concrete workability (machine-ability).

### Why Aggregates Effect Water Demand

- Small boxes have equal volume, but twice the surface area.

**Volume = 2 x 2 x 2 = 8**

**Surface Area = 6 x (2 x 2) = 24**

**Volume = 5 x (1 x 1) = 5**

**Surface Area = 6 x (1 x 1) = 6**

---

**ASTM C 33 - 90  6.1 Fine Aggregate**

<table>
<thead>
<tr>
<th>Sieve Size, (mm)</th>
<th>Sieve Size, (US)</th>
<th>Mass, (g)</th>
<th>Ind. % Retained</th>
<th>Cum % Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>1 1/2&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>75</td>
<td>1&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>37.5</td>
<td>3/4&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>1/2&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9.5</td>
<td>3/8&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.75</td>
<td># 4</td>
<td>25</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>2.36</td>
<td># 8</td>
<td>163</td>
<td>12.9</td>
<td>14.9</td>
</tr>
<tr>
<td>1.18</td>
<td>#16</td>
<td>228</td>
<td>18.0</td>
<td>32.9</td>
</tr>
<tr>
<td>0.6</td>
<td># 30</td>
<td>278</td>
<td>22.0</td>
<td>54.9</td>
</tr>
<tr>
<td>0.3</td>
<td># 50</td>
<td>355</td>
<td>28.1</td>
<td>83.0</td>
</tr>
<tr>
<td>0.15</td>
<td># 100</td>
<td>177</td>
<td>14.0</td>
<td>97.0</td>
</tr>
<tr>
<td>Pan</td>
<td>Pan</td>
<td>38</td>
<td>3.0</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1264</td>
<td>100</td>
<td>2.3 FM</td>
</tr>
</tbody>
</table>
### Moisture Contents of Aggregate

<table>
<thead>
<tr>
<th>State</th>
<th>Ovendry (OD)</th>
<th>Air Dry</th>
<th>Saturated Surface Dry (SSD)</th>
<th>Damp or Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Moisture</td>
<td>None</td>
<td>Less than potential absorption</td>
<td>Equal to potential absorption</td>
<td>Greater than absorption</td>
</tr>
</tbody>
</table>

### Aggregate Moisture

Total Moisture = Free moisture + Aggregate absorbed moisture

\[
\% \text{ Total Moisture Content} = \left( \frac{\text{Wet Wt} - \text{Dry Wt}}{\text{Dry Wt}} \right) \times 100
\]

**Example:**
- Wet Wt = 1000 g
- Dry Wt = 980 g
- \( \frac{1000 - 980}{980} \times 100 = 2.4\% \)

Never include the weight of the pan!

\% Free Moisture = Total Moisture - Absorbed Moisture

### Cement Powder

- C₃S – Tricalcium Silicate
- C₂S – Dicalcium Silicate
- C₃A – Tricalcium Aluminate
- C₄AF – Tetracalcium Aluminoferite

Also used: Anhydrite or Gypsum, CaSO₄·2H₂O
C₃S – Tricalcium Silicate

- Hydrates and hardens rapidly and is largely responsible for initial set and early strength. In general, the early strength of Portland cement is higher with increased percentages of C₃S

C₃S (Dicalcium Silicate)

- Hydrates and hardens slowly and contributes largely to strength increase at ages beyond one week

C₃A – Tricalcium Aluminate

- Liberates a large amount of heat during the first few days of hydration and hardening. It also contributes slightly to early strength development. Gypsum, which is added to cement during final grinding, slows down the hydration of C₃A. Without gypsum, a cement with C₃A present would set rapidly. Cements with low percentages of C₃A are especially resistant to soils and water containing sulfates.

C₄AF – Tetracalcium Aluminoferrite

- Reduces the clinkering temperature, thereby assisting in the manufacture of cement. It hydrates rather rapidly but contributes very little to strength. Most color effects are due to C₄AF and its hydrates.

Types of Cements

- Type I - Normal
- Type II - Moderate Sulfate Resistance
- Type III - High Early Strength
- Type IV - Low Heat of Hydration
- Type V - High Sulfate Resistance

Composition & Fineness of Portland Cements

<table>
<thead>
<tr>
<th>Type</th>
<th>C₃S</th>
<th>C₂S</th>
<th>C₃A</th>
<th>C₄AF</th>
<th>Blaine Fineness</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>17.5</td>
<td>49-62</td>
<td>9-16</td>
<td>6.4</td>
<td>12.7</td>
</tr>
<tr>
<td>II</td>
<td>58.1</td>
<td>51-68</td>
<td>6.4</td>
<td>7.11</td>
<td>7-11</td>
</tr>
<tr>
<td>III</td>
<td>58.0</td>
<td>49-66</td>
<td>3.4</td>
<td>9.1</td>
<td>7-13</td>
</tr>
<tr>
<td>IV</td>
<td>58.2</td>
<td>52-63</td>
<td>3.4</td>
<td>11.7</td>
<td>2.5-3.12</td>
</tr>
<tr>
<td>V</td>
<td>58.7</td>
<td>50.5-72.4</td>
<td>10.4</td>
<td>1.0</td>
<td>7-13</td>
</tr>
<tr>
<td>White</td>
<td>62.7</td>
<td>17.8</td>
<td>0.4</td>
<td>8.4</td>
<td>0.7-1.8</td>
</tr>
</tbody>
</table>
Cement

- ASTM C150 or ASTM C1157 (Performance Standard)
- Cement mill certificates
- Color consistency
- Care
- Correlating deliveries to products

Mill Cert. Control Chart

- Since the raw materials are dug out of the ground, their consistency will vary
- Mixture proportions of the raw materials must be continually adjusted
- Therefore, the cement characteristics will vary

Mill Cert. Control Sheet

- Alkali content
- Blaine fineness
- $C_3S$ – higher %, higher early strength
- $C_2S$ – higher %, higher long term strength
- $C_A$ – lower %, higher sulfate resistance
Alkali Content

- $\text{Na}_2\text{O}$ and $\text{K}_2\text{O}$ shown as Equivalent alkalies on the Cert.
- As alkali content increases, air entraining agents produce more air. If above 0.60%, change of 0.10% significant. If low (0.30%), even 0.05% change significant
- Less than 0.60% necessary if ASR potential

Blaine Fineness

- Controls early strength
- Higher the Blaine, higher the water
- Higher the Blaine, higher the air entrainment admix demand
- Change in Blaine signals a potential change in concrete performance

Blended Cement

- What is it?
- Why use one?
- Material choices
  - Portland blast-furnace slag cement, Portland-Limestone cement, Portland-pozzolan cement
  - Blend cement with SCM, such as Fly Ash (Class C or F), Silica Fume, Slag Cement, Metakaolin
- Advantages/Disadvantages

Mineral Admixtures

- Pozzolans
  - Class F Fly Ash
  - Silica Fume
  - Metakaolin

The Definition of a Pozzolan

- A siliceous (or siliceous and aluminous material) which in itself possess little or no cementitious value
- However, when finely divided (high surface area) and in the presence of moisture (water must be present), pozzolans chemically react with calcium hydroxide to form compounds possessing cementitious properties.
- This occurs at ordinary temperatures
Mineral Admixtures

- Hydraulic
  - Granulated blast furnace slag
  - Class C Fly ash

Fly Ash

- **Class C**
  - “C” ash is *cementitious* and *pozzolanic*
  - Class C ash contains higher CaO contents
    - (8% - 40%)
  - High lime content, light color
    - Due to lower carbon and iron contents
  - ASTM C 618
    - Medium – High CaO (18 – 40%)

- **Class F**
  - “F” ash is *pozzolanic*
  - Class F ash contains low CaO content
    - (1-15%)
  - Low lime content, dark color
    - Due to presence of unburned carbon
  - ASTM C 618
    - Low CaO (2-15%)

Fly Ash Features and Benefits

- Reduced permeability
- Increased resistance to alkali-silica reactivity
  - Primarily Class F
  - 25% to 40% of total cementitious
- Increased resistance to sulfate attack
  - Primarily Class F
  - 20% to 50% of total cementitious
- Reduces mix costs
- Significant long term strength gain
  - Delayed with Class F
  - Improved concrete mix workability
  - Reduced bleeding
  - Reduced heat of hydration
    - Primarily Class F
    - Greater than 20%
    - 20 - 30% replacement can meet Type IV

- Reduced permeability
- Increased resistance to sulfate attack
Fly Ash
Cautions

- Fly ash can affect air entrainment dosages (decrease the amount of air entrainment)
- Increase initial set time
- Lower early strengths

Molten Blast Furnace Iron & Slag

Slag Cement (GGBFS)

- **ASTM C 989 Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete** (classified by Strength Activity Index compared to a reference Portland Cement)
  - Grade 80 (SAI @ 28days = 75%)
  - Grade 100 (SAI @ 7days = 75% & 28days = 95%)
  - Grade 120 (SAI @ 7days = 95% & 28days = 115%)

GGBFS is a hydraulic SCM

Slag Features and Benefits

- Benefits for Hardened Concrete
  - Higher 28-day strength
  - Increased flexural strength
  - Lighter, brighter color (substitute for white cement)
  - Increased ability to reflect solar heat
  - Reduced permeability and increased durability

Other Pozzolans

- **Silica fume (microsilica)**: pure, amorphous silica with particle size of 0.1-0.2 μm, collected during the manufacture of silicon and ferrosilicon alloys. Very fine — surface area of 20,000 sq. m/kg (smoke is 10,000)
- **Metakaolin**: an aluminosilicate obtained by calcination of china (kaolin) clay
**General Properties**

- The relative density of silica fume is roughly 2.2 (between 2.2 and 2.5) (3.15 opc)
- In general, the water demand is increased
- Generally used between 5 and 10% of the mass of the cement material (7-8% typical)
- Mixtures typically reported as ‘sticky’
- Curing should start as soon as possible
- Improve durability and strength

**Other SCM Considerations**

- Must accommodate specific gravity difference when batching with fly ash and slag
  - Specific gravity of fly ash = 2.2 - 2.8
  - Specific gravity of ggbs = 2.6 - 2.9
  - Specific gravity of Portland cement = 3.15
- Must adequately cure concrete when slow hydration occurs
Don’t just add water!

Abrams’ Law defines w/c ratio. Water is the single most important element in the quality of concrete manufacturing.

The more water used:
- the lower the compressive strength
- the lower the impermeability
- the lower the freeze-thaw resistance
- the lower the resistance to de-icing salts
- the lower the durability
- if you add just one gallon of water to a cubic yard of properly designed 3,000 psi concrete mix:
  - you increase the slump by about 1”, but increase the spread of SCC by 3”
  - you cut the compressive strength by as much as 200 psi
  - you waste the effect of a ¼ bag of cement
  - you increase the shrinkage potential about 10%
  - you decrease the strength gain by about 30%
  - you decrease the resistance to de-icing salts
  - you lower the quality of concrete in many other ways

Entrapped Air

- Undesirable
- Air trapped during mixing and placement process
- Large, non-uniform voids, visually observed
- Removed or reduced through proper mixing & vibration

Entrained Air

- Air-entraining admixtures produce a uniform network of small spherical voids/bubbles
- Need large number of small air bubbles (10 billion per CY)

Freezing Behavior (Air Entrained Concrete)

- There are ‘air-filled’ pores in the system
- The AE pores are air-filled
- These pores act as a shock absorber and allow the water a place to go as it freezes as the temperature drops
- As the temperature drops the water in the capillary pores expands but water is also going toward the AE pores
- Under pressure the water will be pushed into the AE pores and not crack the paste
Entrained Air - Benefits

- Increased resistance to freezing and thawing, and frost damage
- Improves workability
- Reduces sedimentation, bleed water and segregation on long hauls

Entrained Air - Disadvantages

- Reduces strength (5 to 10% for each 1% of air)
- High air-contents make mixtures sticky and difficult to finish

Entrained Air - Test

- Plastic air- Gravimetric, Volumetric and Pressure meter
- Hardened Air - Petrographic analysis ASTM C 457
  - Air-content 2% to 3%
  - Water flow in hardened concrete about 0.01

Propportioning

1. Absolute Volume Method
2. Other Methods
   - ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavy Weight and Mass Concrete
   - ACI 211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete
   - ACI 211.3 Standard Practice for Selecting Proportions for No-Slump Concrete
   - ACI 211.4R Standard Practice for Selecting Proportions for High Strength Concrete with Portland Cement and Fly Ash
   - ACI 211.5 Guide for Submittal of Concrete Proportions
Some Standards

• Typical values and quantities used in mix designs:
  - Water
  - Cement

• Specific gravity
  - Water: 1.00
  - Cement: 3.15

• Unit weight
  - Water: 62.4 lbs/ft³
  - Cement: 94 lbs/bag

• Also need to know that 7.5 gal (water) = 1 ft³
  - 27 ft³ = 1 yd³
  - 1 ton = 2000 lbs

• Yield = ft³ or yd³ of concrete produced from the combined weights of all the materials in the batch.

• Cementitious materials = cement, fly ash, silica fume, slag, etc.

Specific Gravity

The specific gravity of any material is the weight of the material in air divided by the weight of an equal volume of water. For example, an aggregate with a specific gravity of 2.50 would be two and one half times as heavy as water for the same volume.

- Water (SG = 1.00)
- Aggregate (SG = 2.50)

  (If the volumes are equal)

  1.00 pound                                            2.50 pounds

Density equals mass per unit volume

Aspects of the ‘Required Strength’

• $f_{cr}$ = required compressive strength
• $f_c$ = specified compressive strength
• $s$ = standard deviation

- $f_c$ shall not be less than 2500 psi
- $f_c$ shall be based on tests of compressive cylinders
- $f_c$ shall be based on 28 day strength unless otherwise stated
- $f_o$ generally 500 to 700 psi higher as determined on the following slides

Terminology

Concrete Mix Design

• It’s always about volume!
  - Pounds of Material / S.G. X 62.4 = Absolute Volume

• It’s always about materials!
  - Specific gravity of Type I Cement = 3.15 (always ??)
  - Specific gravity of water = 1.0
  - 1 gallon of water weights 8.33 pounds
  - Water weights 62.4 pounds / cubic foot

Finally... STEPS IN DESIGNING A CONCRETE MIX following the absolute volume method given in ACI 211.1

• Step 1. Choose slump. See Table 6.3.1
• Step 2. Select maximum size aggregate.
• Step 3. Estimate mixing water and air content. Table 6.3.3
• Step 4. Select W/CM ratio. Table 6.3.4 (a) and (b)
• Step 5. Calculate cement content.
• Step 6. Estimate coarse aggregate content. Table 6.3.6
• Step 7. Estimate fine aggregate content.
• Step 8. Adjust for aggregate moisture.
• Step 9. Make adjustments based on trial batch results.
Assume: CA 55%, FA 45%.

**MATERIAL WEIGHT (lbs.)** | S.G. | **VOLUME (cu.ft.)**
--- | --- | ---
Cement | 580 | 3.15 | 580/(3.15 x 62.4) = 2.95
CA | 1830 | 2.68 | 1830/(2.68 x 62.4) = 3.35
FA | 1441 | 2.58 | 1441/(2.58 x 62.4) = 8.95
Water | 209 | 1.00 | 209/62.4 = 3.35
Air | 0% | 0.81

**Adjusted Batch Weights**

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Weight (lbs.)</th>
<th>Batch Weight (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>580</td>
<td>580</td>
</tr>
<tr>
<td>CA</td>
<td>1830</td>
<td>1867</td>
</tr>
<tr>
<td>FA</td>
<td>1441</td>
<td>1520</td>
</tr>
<tr>
<td>Water</td>
<td>209</td>
<td>93</td>
</tr>
<tr>
<td>Air</td>
<td>0%</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Unit Weight** = \( \frac{4060}{27} = 150.37 \) lbs./cu.ft.

**Batch Weight**

\[
\text{Batch Weight} = \text{Material Weight} \times \text{Batch Weight Factor} + \text{Weight of Moisture}
\]

W/C on = 0.36

\[
2.36 \times 0.84 + 3.35 + 0.81 = 7.36 \text{ cu ft.}
\]

Aggregates = 7.36 x 10.64 cu ft.

Assume: CA 55%, FA 45%.

**CA**

\[
\text{W/C} = 0.36 \times 2.58 \times 62.4 = 1441 \text{ lbs.}
\]

**FA**

\[
\text{W/C} = 0.36 \times 2.68 \times 62.4 = 1441 \text{ lbs.}
\]

**Weight of Moisture**

\[
\text{Weight of Moisture} = 1830 \times \frac{6}{100} = 116 \text{ lbs.}
\]

\[
\text{Weight of Moisture} = 1441 \times \frac{2}{100} = 28.8 \text{ lbs.}
\]

\[
\text{Weight of Moisture} = 1441 \times \frac{5.5}{100} = 80.6 \text{ lbs.}
\]

\[
\text{Adjusted Batch Weights} = \text{Material Weight} + \text{Weight of Moisture}
\]

**Batch Weight**

\[
\text{Batch Weight} = 1441 + 116 = 1520 \text{ lbs.}
\]

\[
\text{Batch Weight} = 1441 + 28.8 = 1500 \text{ lbs.}
\]

\[
\text{Batch Weight} = 1441 + 80.6 = 1521 \text{ lbs.}
\]

**Volume**

\[
\text{Volume} = \frac{\text{Material Weight}}{\text{S.G.}}
\]

\[
\text{Volume} = \frac{1441}{3.35} = 430 \text{ cu ft.}
\]

\[
\text{Volume} = \frac{1830}{2.68} = 682 \text{ cu ft.}
\]

\[
\text{Volume} = \frac{1441}{2.58} = 560 \text{ cu ft.}
\]

\[
\text{Volume} = \frac{209}{1.00} = 209 \text{ cu ft.}
\]

\[
\text{Volume} = \frac{0}{0.81} = 0 \text{ cu ft.}
\]
Self Consolidating Concrete

Polycarboxylate Attributes

- Low dosage
  - 2-4 times as potent as previous generations of water-reducing admixtures
- Improved workability and slump retention
- Less likely to segregate at SCC consistencies
- Linear water reduction

40% or greater water reduction potential with minimal retardation

Better workability and finishability compared to high-range water reducers

Increased early and ultimate strengths

Self-Consolidating Concrete

- SCC
- Japan since 1987
- To USA in 2000
- Flows like liquid
- Measure spread, not slump
- No vibration needed
- Will not segregate, if designed correctly
- Expensive supers
- Fewer bug holes, smoother finish
- More cement and fines
- Up to 20% Fly Ash improves the stability of SCC mixes

Cautions

- Material cost can be as much as 20% more
- Use low W/Cm ratio
- Longer mixing time because more powder and longer to disperse admix in the mix
- SCC mixes extremely sensitive to changes in moisture and aggregate gradation
- Pouring too quickly can cause segregation
- Work very closely with your admix supplier – not all admixes are the same

Cautions (cont’d)

- Aggregates need to be well graded to achieve maximum density
- Affected by aggregate shape – marbles, dice, dominos
- Can sometimes save a wet mix by adding VMA
Cautions (cont’d)

- Design the forms for full hydraulic pressure
- Any defects in forms will become even more visible
- Ensure forms level as SCC will self-level and not follow the slope
- Can segregate during transportation if distance too far and/or ground surface bumpy

Root Beer Float

- "Root Beer Float" – excess water can result in a creamy, bubbly foam at the surface (segregation)
- Using vibrators can cause segregation – if have a black line, hit side of form with rubber mallet
- Must “wet out” the mix – mix long enough to disperse the admix throughout the mix
- Accelerating curing before initial set can increase the number of large voids

Cautions (cont’d)

- Bugholes can be caused by
  - pouring too quickly
  - pouring in too many places (Vortex)
  - changing form oil
  - change in aggregate gradation

SCC Tests

- ASTM C1611 – Slump Flow Test – take the average of two measurements
- T20 Test – measure time (2 – 5 secs) at spread of 20” (varies with aggregate type – marbles, cubes, dominos)
- Finger Test – run finger through the spread to compare how quickly the groove closes, and shape of the groove

SCC – slump flow
T-20 Test

- New generation of water-reducing technology

‘Unofficial’ Finger test

Viscosity Modifying Admixtures

- VMA’s increase the viscosity of the concrete paste fraction thereby reducing the likelihood of segregation

SCC Tests (cont’d)

- ASTM C1621 – J-Ring Test to measure passing ability of mix through the reinforcing steel
What is Blocking?

Size, volume, & blend of aggregate require sufficient volume of paste to flow “Passing ability”

SCC Tests (cont’d)

- ASTM C1610 - Column Segregation Test
- ASTM C1712 – Rapid Assessment Method for SCC segregation
- U-Box Test
- V-Funnel Test
- ACI 237 to determine pressure on forms
ASTM C-1712
Rapid Assessment Method for SCC Segregation

Penetration Depth (PD) and Different Stability Levels

- Highly Stable (PD ≤ 10 mm)
- Stable (10 mm < PD ≤ 25 mm)
- Unstable (PD > 25 mm)

L Box Test

- Test for blocking (ability to pass through rebar or obstructions), indicated the difference in concrete height between H1 and H2
- Check surface appearance of mix for indication of tendency to segregate (no aggregates visible on surface)

Blocking ratio = H2/H1

BR = 1.0 is Excellent
BR = 0.9 Acceptable

U Box Test

Concrete must reach at least 30 cm height after passing through rebar

V Funnel Test

VSI (Visual Stability Index)

0 - Highly Stable
   No evidence of segregation

1 - Stable
   No mortar halo*
   No aggregate pile in the slump spread
   Some slight bleeding

2 - Unstable
   slight mortar halo* (<10 mm)
   aggregate pile in the center of the slump spread

3 - Highly Unstable
   clear segregation, noticeable halo* (>10 mm)
   large or considerable aggregate pile in the slump spread

*halo: mortar ring in that paste separated from the aggregate
SCC vs. Flowing Concrete

Exposed Aggregate, extreme leading paste "3"

No Halo, No Segregation “0”

SCC Proportioning Steps

- Determine required slump flow
- Select coarse aggregate size
- Determine the required air content
- Estimate the required powder content
- Estimate the required water content
- Calculate coarse and fine aggregate amounts after Powder, Water and Air contents are determined
- Calculate paste and mortar volume
- Adjust coarse and fine aggregate weights based on paste and mortar volumes
- Select admixture types and dosage
- Batch Trial Mixture – Make adjustments and batch again

Possible Powder Content

<table>
<thead>
<tr>
<th>Property</th>
<th>Powder Content</th>
<th>Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluidity</td>
<td>Too Low</td>
<td>Too Low</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Too Low</td>
<td>Too High</td>
</tr>
<tr>
<td>Insufficient Passing Ability</td>
<td>Too Low</td>
<td>Too High</td>
</tr>
<tr>
<td>Stability</td>
<td>Excessive Segregation Aggregate Pile</td>
<td>Too High</td>
</tr>
<tr>
<td>Mortar Halo</td>
<td>Too High</td>
<td>Too High</td>
</tr>
</tbody>
</table>

Adjustments to mix

Placement examples

- Good for products with:
  - Thin walls
  - High potential for honeycombing and bug holes

- Typical size: from 12 - 15 yd³ (9 - 12 m³) to products as small as MH and septic tanks
Production

- Form requirements
  - Relatively tight/level (low viscosity SCC)
  - Accommodate full hydrostatic pressure
- Coordinate batching speed with placement speed
- Fill transport equipment appropriately
- Large discharge = enhanced flowing
- Can be placed by all conventional methods (pump, chute, bucket)

SCC Lessons Learned

- Horizontal flow is best
  - Avoid free-fall
- No vibration necessary
- Minimal screeding or bullfloating required
- Finish as desired – evaluate timing
- Curing is essential

Conventional placement method

- Free fall concrete into itself

The result...

- Creates a “vortex”, entrapping significant quantity of air voids

SCC Placement

- High slump flow
- Continuous supply preferred
Purpose of Reinforcement

- Concrete properties
  - Strong in compression
  - Weak in tension

- Reinforcement supplies strength to withstand tensile and shear forces experienced by concrete

Concrete Under Compression

This 2” X 2” cube of concrete withstands a 4000 psi compressive force
Concrete in Tension

The same 2” X 2” cube of concrete fails under a 400 psi tensile force

Flexural Forces on Concrete

Without reinforcement, the bottom side will fail in tension

Reinforced Concrete Behavior

Concrete Behavior Under Shear

• Vertical Shear

Concrete Behavior Under Shear

• Horizontal Shear, Shear Reinforcement
### Reinforcement Types
- Reinforcing bars
- Reinforcing wire
- Bar mats and welded wire fabric
- Zinc or epoxy coated reinforcement

### Reinforcing Bars
- Conform to specifications
  - ASTM A615 (New Billet)
  - ASTM A616 (Rail)
  - ASTM A617 (Axle)
  - ASTM A706 (Weldable)
- Other bars may be used if permitted by design
- Mill certificates required for each shipment

### Effectiveness of Placement
- **0.01” Crack in Pipe**
- **Deflection Under Test Condition**
- **Stress Zones Under Test Condition**
  - Red: Tension
  - Gray: Compression
Steel Area Using Different Combinations of Bar Sizes and Spacing

<table>
<thead>
<tr>
<th>Size</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
<th>#7</th>
<th>#8</th>
<th>#9</th>
<th>#10</th>
<th>#11</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 in</td>
<td>1.20</td>
<td>1.76</td>
<td>2.34</td>
<td>3.96</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 in</td>
<td>0.80</td>
<td>1.24</td>
<td>1.86</td>
<td>2.40</td>
<td>3.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 in</td>
<td>0.60</td>
<td>0.93</td>
<td>1.32</td>
<td>1.80</td>
<td>2.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 in</td>
<td>0.48</td>
<td>0.74</td>
<td>1.06</td>
<td>1.44</td>
<td>1.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 in</td>
<td>0.40</td>
<td>0.62</td>
<td>0.88</td>
<td>1.20</td>
<td>1.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 in</td>
<td>0.34</td>
<td>0.53</td>
<td>0.75</td>
<td>1.03</td>
<td>1.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 in</td>
<td>0.30</td>
<td>0.47</td>
<td>0.66</td>
<td>0.90</td>
<td>1.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 in</td>
<td>0.27</td>
<td>0.41</td>
<td>0.59</td>
<td>0.80</td>
<td>1.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 in</td>
<td>0.24</td>
<td>0.37</td>
<td>0.53</td>
<td>0.72</td>
<td>1.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 in</td>
<td>0.22</td>
<td>0.34</td>
<td>0.48</td>
<td>0.65</td>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 in</td>
<td>0.20</td>
<td>0.31</td>
<td>0.44</td>
<td>0.60</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 in</td>
<td>0.18</td>
<td>0.29</td>
<td>0.41</td>
<td>0.55</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 in</td>
<td>0.17</td>
<td>0.27</td>
<td>0.38</td>
<td>0.51</td>
<td>0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 in</td>
<td>0.16</td>
<td>0.25</td>
<td>0.35</td>
<td>0.48</td>
<td>0.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 in</td>
<td>0.15</td>
<td>0.23</td>
<td>0.33</td>
<td>0.45</td>
<td>0.59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 in</td>
<td>0.14</td>
<td>0.22</td>
<td>0.31</td>
<td>0.42</td>
<td>0.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 in</td>
<td>0.13</td>
<td>0.21</td>
<td>0.29</td>
<td>0.40</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reinforcing Wire

- Conform to (except prestressing wire)
  - ASTM A82 (A1064)
  - ASTM A496 (A1064)
- Other wire may be used if permitted by design
- Mill certificates for each shipment

Bar Mats and Welded Wire Fabric

- Conform to
  - ASTM A184
  - ASTM A185 (A1064)
  - ASTM A497 (A1064)
- Mill certificates for each shipment.
- Applications of rolled vs. straight

Welded Wire Fabric

- Must conform to ASTM A 185 (A1064) “Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement”
- Welded intersections must be spaced not more than 12 in.
Welded Deformed Wire Fabric

- Must conform to ASTM A 497 (A1064) “Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement”
- Welded intersections must be spaced not more than 16 in.

Section at typical weld showing complete fusion of intersecting wires.

Structural integrity depends on

- Size of the reinforcing steel
- Spacing of the reinforcing steel
- Positioning of the reinforcing steel
- Grade of the reinforcing steel
Minimum Bend Diameters

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Minimum Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.3 - No.8</td>
<td>6dₜ</td>
</tr>
<tr>
<td>No.9, No.10, No.11</td>
<td>8dₜ</td>
</tr>
<tr>
<td>No.14 and No.18</td>
<td>10dₜ</td>
</tr>
</tbody>
</table>

dₜ = diameter of the bar

Not for Hooks or Stirrups

Factors affecting minimum bend diameters:
- Feasibility of bending without breaking
- Avoidance of concrete crushing inside the bend
- Welded wire fabric
  - W7 and smaller: 1dₜ
  - Larger than W7: 2dₜ
  - D6 and smaller: 2dₜ
  - Larger than D6: 4dₜ
ASTM C76 Lap Requirement (same for C478)

- Section 8.1.8 states “If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.”

ASTM C76 (cont’d) (same for C478)

- Section 8.1.8.1 states “When splices are welded and are not lapped to the minimum requirements above, there shall be a minimum lap of 2 in. and a weld of sufficient length such that a pull test of representative specimens shall develop at least 50% of the minimum specified tensile strength of the steel. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75% of the minimum specified strength of the steel.”
**ASTM C478 Splice Requirement**

- Section 6.4.2 is the same as Section 8.1.8.1 of C76
- Section 6.5 for hoop steel states “A representative sample steel hoop with welded splices shall develop at least 50% of the minimum specified strength of the steel, and there shall be a minimum lap of 2 in. For butt-welded splices, the representative steel hoop sample shall develop at least 75% of the minimum specified strength of the steel.”

**NPCA QC Manual**

- Welding of reinforcement
  - Maintain product integrity
  - Two weldability limits
    - Max. Carbon content (0.30%) [AWS D1.4]
    - Carbon equivalent (CE)
      - A318 and AWS D1.4, CE are:
        - For #6 and smaller - 0.55% Max.
        - For #7 and larger - 0.45% Max.
        - The lower the CE, the better the weldability
        - For larger CE values, the rebar must be preheated

**ASTM A 615 Reinforcement**

- ASTM A615 rebar
  - Must be used with extreme caution
  - Generally not acceptable
  - Check CE = %C + %Mn/6

**ASTM A 706 Reinforcement**

- ASTM A706 rebar
  - Is a low-alloy weldable grade
  - Check CE = %C + %Mn/6 + %Cu/40 + %Ni/10 + %Cr/10 - %Mo/50 - %V/10
The Precast Show

Form Maintenance

Magnetic Chamfer Strips
Cleaning
- Clean forms after each use
- Minimize over cleaning
  - Can expose raw metal
- Use scrapers, putty knife, air compressors
- Copper/wool brushes less abrasive than steel
- Season forms
- Remove rust with steel brush/wool and season again
- Avoid grinding and banging off with hammers

Seasoning
- Remove protective coating to prevent staining, sticking, poor finish
  - Wear off during production
  - Solvents
  - Grind
  - Blast
- Apply high fatty acid concentrate release agent; Let it react (forms metallic soap barrier). If using a barrier agent, use it for seasoning.
- Allow 24-hr sit-time
- Clean off soap, leaving a protective film
- Put into use
Categories of Release Agents

- Barrier (non-reactive)
- Chemically Active
- Combination of above

Barrier (non-reactive)

- Examples
  - Petroleum-based diesel, heating oils, used crankcase oil
- Advantages
  - Creates a physical barrier between form and fresh concrete
- Disadvantages
  - Need heavy application for easy release (200-400 ft²/gal)
  - Can cause staining and bugholes
  - Will not meet VOC requirements

Chemically Reactive

- Examples
  - Fatty acids (vegetable and mineral oils) are chemically reactive agents that combine with calcium in fresh cement paste to produce a soap-like film between the concrete and the form
- Advantages
  - Prevents bonding of concrete to form
  - Ultra-thin Layer (≈0.005”)
  - Reduce bugholes, stains, dusting
  - Meets VOC requirements
- Disadvantages
  - More Costly per gallon

Consolidation

- Consolidation
  - Even distribution of all ingredients in the mix
- Compaction
  - Packing of concrete
  - Remove air
- Vibration
  - Pressure waves separate aggregate particles by reducing friction
  - Remove air
Why Vibrate?

- Freshly placed wet cast concrete can contain as much as 20% entrapped air
- Proper vibration increases density by driving out entrapped air
- Results in:
  - Optimum strength
  - Durability
  - Quality appearance
  - Watertightness

Vibration will

- Eliminate voids and honeycombs
- Release entrapped air
- Fully encase reinforcement, embedded items, and blockouts with fresh concrete

THE THEORY

- MASS
- FREQUENCY
- AMPLITUDE
- ACCELERATION
- FORCE

Frequency

It is how many RPM or VPM that the vibrator shaft rotates.

3450  3600  6000  7200  10,000  17,000

Amplitude

It is affected by frequency....
The higher the frequency the lower the amplitude.
Which means the lower the frequency the higher the amplitude.
### Amplitude & Frequency of Vibration

- Both necessary for proper consolidation
  - **Frequency**
    - Number of vibration cycles per minute
    - Expressed as rpm or vpm
    - Speed
  - **Amplitude**
    - Maximum distance a point on the vibrator head moves from its position of rest
    - Shake or Impact

### Methods of Vibration

- **INTERNAL** – Stingers (flexible shaft or immersion)
- **EXTERNAL** – Mounted on forms both jacket and core. Vibrating tables

### Factors to Consider Selecting Method

- Product configuration
- Reinforcement configuration
- Mix design
- Aggregate size
- Size and rate of concrete placement
- Desired finish

### Internal Vibration

- Form vibration more common for dry cast production
- Stinger (spuds, sticks, pokers, pig stickers) most common

### Amplitude & Frequency

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects Heavier Mass</td>
<td>Effects Lighter Mass</td>
</tr>
<tr>
<td>Moves the Aggregate</td>
<td>Moves Sand &amp; Slurry around Aggregate</td>
</tr>
<tr>
<td>Determines Radius of Action</td>
<td>Governs Liquefication</td>
</tr>
</tbody>
</table>

### Internal Vibration

- (electric, hydraulic, pneumatic)
- Stingers - commonly used for smaller wet cast items and flat work
Stinger Vibrators

- **Rule of Thumb**
  - The Head Diameter should be approximately
    - Wall Thickness 4

It is important to assess your common cage configurations.

Vibration Frequency

- Increasing frequency from 6000 to 7500 vpm doubles the energy output
- Increasing from 7500 to 9500 vpm, doubles it again
- 17000 vpm delivers more consolidation faster, but beware if air entraining (removes air bubbles)

Stinger Vibration Procedure

- Drop vertically under own weight (~1 sec/ft)
- Withdraw slightly slower than inserted (~3 sec/ft)
- Place stick into each area only once
- Overlap vibrating radius
- When layering concrete, place stick ~6” into previous layer
- Vibrate until surface is shiny and level, and no more breaking bubbles
- Avoid touching formwork

Overlapping Field of Action

Effect of not overlapping field of action

- Reduced strength and durability because of:
  - voids
  - honeycombing
  - entrapped air
  - reinforcement not covered

Time and Frequency of Stinger Vibrators

- Vibration time depends on frequency
  - The higher the frequency, the less vibration time needed
- Frequency reduced by 20–25% when immersed in concrete
Effects of not overlapping field of action

Reduced strength and durability because of:
- voids
- honeycombing
- entrapped air
- Reinforcement not covered

Stinger Vibration Procedure

- Drop vertically under own weight (~1 sec/ft)
- Withdraw slightly slower than inserted (~3 sec/ft)
- Place stick into each area only once
- Overlap vibrating radius
- When layering concrete, place stick ~ 4” into previous layer
- Vibrate until surface is shiny and level, and no more breaking bubbles
- Avoid touching formwork

External Vibration

- Form
- Table

Form Vibration

- Rotary or Linear - Use unbalanced weight
- Electric, pneumatic, hydraulic
- Faster than stick vibration but forms must be stronger
- Don’t fasten vibrator directly onto the form.
- Mounting brackets should be welded onto a form stiffener.

Form Deflection Prevention
What size goes on which form?

THE CONCEPT IS QUITE SIMPLE....

ENOUGH VIBRATION TO CONSOLIDATE THE CONCRETE WITHOUT DESTROYING THE FORM!!!!

Form Vibration Sizing

- 3” Slump:
  - Total Form And Concrete Weight = Vibrator Force
- 1”-2” Slump:
  - 1.3 to 1.75 (Total Form and Concrete Weight) = Vibrator Force
- 0 Slump:
  - 2 to 3 (Total Form And Concrete Weight) = Vibrator Force

Form Vibration

- Mounting brackets should be welded onto the stiffener.
  - Don’t fasten vibrator directly onto the skin.
Torque

- Vibrator bolts must be properly torqued to manufacturers recommendations!!!
Table Vibration

- Rotary or linear vibrators
- Shaker tables - eccentric shaft
- With rotary vibrators, vibration must be unidirectional to avoid “walking” the concrete
- Sizing
  - Use vibrator with an impact force that is 1.5 to 2 times larger than the weight of the concrete plus the weight of the form

Unidirectional Vibration

<table>
<thead>
<tr>
<th></th>
<th>Lighter, Thinner Sections</th>
<th>Heavier, Thicker Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Frequency</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Effects of Under-Vibration

- Can have serious detrimental effects
- Inadequate Concrete Strength & Durability
  - Excessive entrapped air
  - Unbonded Reinforcement
  - Honeycombing
- Poor Appearance
  - Honeycombing
  - Sand streaks
  - Bugholes
The Precast Show

Effects of Over-Vibration

- Segregation
- Form deflection and Damage
- Sand streaks

Curing

- Hardening of concrete
- Normal curing cycle (28 Days)
- Hydration $\rightarrow$ CSH gel
  - Reduces size of voids
- Accelerated curing
  - More important for low w/c ratios
Curing Essential Because

- Reduces permeability
  - Essential for structure watertightness
- Improves durability
- Increases early strengths

Essential for Proper Curing

- Maintain moisture
- Maintain temperature

Concrete Strength vs Moisture Condition

- Proper Moisture and Temperature Result in Increased Concrete Strength

Low Pressure Steam Curing

- Provides both heat and humidity
- Product is heated by the warmer steam condensing on it
- Moisture evaporation is minimized
- Additional moisture is provided by the condensation of steam on the product

Typical Accelerated Steam Curing Cycle

- Preset (Pre-steaming) – at least one hour
- Ramp (Temperature Rise) – at 20°F to 40°F per hour
- Hold (at target temperature) – varies with the product
- Soak (Cooling)
**Idealized Accelerated Curing Cycle**

- 1) Pre-steaming
- 2) Ramping
- 3) Holding *
- 4) Cooling

* For type III or high-early-strength cement, longer for other types

**Target Temperatures**

- **Concrete Pipe**
  - 120°F to 140°F (50°C to 60°C)
  - 4 to 6 hours
- **Precast/Prestress**
  - 140°F (60°C) in Canada
  - 160°F (71°C) in USA
  - 8 to 12 Hours
Since the raw materials are dug out of the ground, their consistency will vary. Mixture proportions of the raw materials must be continually adjusted. Therefore, the cement characteristics will vary.

- Alkali content
- Blaine fineness
- $C_3S$ – higher %, higher early strength
- $C_2S$ – higher %, higher long term strength
- $C_3A$ – lower %, higher sulfate resistance
Alkali Content

- Na$_2$O and K$_2$O shown as Equivalent alkalies on the Cert.
- As alkali content increases, air entraining agents produce more air. If above 0.60%, change of 0.10% significant. If low (0.30%), even 0.05% change significant
- Less than 0.60% necessary if ASR potential

Blaine Fineness

- Controls early strength
- Higher the Blaine, higher the water
- Higher the Blaine, higher the air entrainment admix demand
- Change in Blaine signals a potential change in concrete performance

Aggregate Specifications

- ASTM C33 - Normal Weight Aggregates – be familiar with the required tests
- ASTM C330 - Lightweight Aggregates
- ASTM C637 - Radiation Shielding Aggregates (Heavyweight – Hematite, steel shot, steel shavings)

Reinforcing Wire

- Conform to (except prestressing wire)
  - ASTM A82 (A1064)
  - ASTM A496 (A1064)
- Other wire may be used if permitted by design
- Mill certificates for each shipment

Bar Mats and Welded Wire Fabric

- Conform to
  - ASTM A184
  - ASTM A185 (A1064)
  - ASTM A497 (A1064)
- Mill certificates for each shipment.
- Applications of rolled vs. straight
Quality Assurance

- Plan, typically associated with the owner
- All those planned and systematic actions necessary to ensure that a final product or service will satisfy given requirements for quality and performance.
- QA is how are we going to get what we paid for
- QC is the implementation of QA

Quality Control

- What is Quality Control.....?
- What is Quality Assurance..... ?
  - What do you think........?

The single most important factor in quality control is management commitment to produce quality products. Management must implement a quality control program that monitors quality and reports on conformance with requirements.

Qualified personnel are also required.

NPCA QC Manual, page 2
**NPCA Plant Certification Program**

**Purpose**
- Consistently achieve a high degree of excellence in plant facilities, production, procedures, and QC operations
- Assist management in achieving excellence in plant operations
- Provide recognition
- Help precast users and specifiers identify and select high quality producers

**Scope**
- Plants are qualified to produce precast products with a high degree of excellence

**Qualification**
- Score overall 80% or better, 75%- probationary
- 75% or better in each of the critical requirements
- Critical requirements, General:
  - Concrete Testing
- Critical requirements, Pipe:
  - Reinforcing Steel inspection
  - Three-edge-bearing test
  - Absorption testing

**Qualification, Manholes:**
- Reinforcing Steel inspection

**Qualification, Box Culverts:**
- Pre-Pour Inspections
- Dimensional checks

**Qualification, Septic Tank:**
- Water Tightness testing

**Grading**
- Heavily influenced by good production practices and quality control operations

**Specifications, Standards, and References**
- ACI, ASTM, AWS, CRSI Standards
- PCI, PCA, WRI publications

**Concrete Testing**
- Sampling, ASTM C172
- Temperature, ASTM C1064
- Slump, ASTM C143
- Unit weight, yield, and air, ASTM C138
- Air content (pressure) ASTM C231
- Air content (volumetric) ASTM C173
- Concrete test cylinders, ASTM C31

**Drawings**
- Absolute accuracy in detailing
- Sound engineering design
- Clarity, readability, completeness
- Timeliness
- Status - preliminary or approved
- Revisions
- Retention duration
Aggregate Testing

- Gradation
- Organic impurities
- Moisture content
- Others - hardness, absorption, & alkalinity reactivity

Record Keeping

- What goes in? Where do I find it? What do I do with it?
- Raw material test records
- Work orders and product drawings
- Equipment calibration records
- Aggregate and concrete test records
- Concrete batching reports
- General plant and product inspection records
- Training performed; personnel qualifications
Questions?
Material Certification Report

Material: Portland Cement
Type: I-II(MH)

Certification
This Holcim cement meets the specifications of ASTM C150 for Type I-II(MH) cement, and complies with AASHTO M85 specifications for Type I-II(MH) cement.

General Information
Supplier: [Redacted]
Address: [Redacted]
Telephone: [Redacted]
Date Issued: 15-Dec-2015
Source Location: [Redacted]
Contact: [Redacted]

The following information is based on average test data during the test period. The data is typical of cement shipped by Holcim; individual shipments may vary.

Tests Data on ASTM Standard Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Chemical</th>
<th>Limit</th>
<th>Result</th>
<th>Item</th>
<th>Physical</th>
<th>Limit</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ (%)</td>
<td>-</td>
<td>19.8</td>
<td>-</td>
<td>Air Content (%)</td>
<td>12 max</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Al₂O₃ (%)</td>
<td>6.0 max</td>
<td>4.7</td>
<td>-</td>
<td>Blaine Fineness (m²/kg)</td>
<td>250-430</td>
<td>379</td>
<td>-</td>
</tr>
<tr>
<td>Fe₂O₃ (%)</td>
<td>6.0 max</td>
<td>3.3</td>
<td>-</td>
<td>Autoclave Expansion (%) (C151)</td>
<td>0.80 max</td>
<td>-0.01</td>
<td>-</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>-</td>
<td>64.1</td>
<td>-</td>
<td>Compressive Strength MPa (psi): 3 days</td>
<td>10.0 (1450) min</td>
<td>29.8 (4320)</td>
<td>-</td>
</tr>
<tr>
<td>MgO (%)</td>
<td>6.0 max</td>
<td>1.3</td>
<td>-</td>
<td>7 days</td>
<td>17.3 (2470) min</td>
<td>35.3 (5230)</td>
<td>-</td>
</tr>
<tr>
<td>SO₃ (%)</td>
<td>3.0 max</td>
<td>3.1</td>
<td>-</td>
<td>Initial Vicat (minutes)</td>
<td>45-375</td>
<td>115</td>
<td>-</td>
</tr>
<tr>
<td>Loss on Ignition (%)</td>
<td>3.0 max</td>
<td>2.1</td>
<td>-</td>
<td>Mortar Bar Expansion (%) (C1038)</td>
<td>-</td>
<td>0.002</td>
<td>-</td>
</tr>
<tr>
<td>Insoluble Residue (%)</td>
<td>0.75 max</td>
<td>0.18</td>
<td>-</td>
<td>Heat of Hydration: kJ/kg (cal/g)</td>
<td>-</td>
<td>333 (80)</td>
<td>-</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>-</td>
<td>1.1</td>
<td>-</td>
<td>7 Days (for informational purposes)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Limestone (%)</td>
<td>5.0 max</td>
<td>2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CaCO₃ in Limestone (%)</td>
<td>70 min</td>
<td>92</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Inorganic Processing Addition (%)</td>
<td>5.0 max</td>
<td>0.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Potential Phase Compositions:</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C₃S (%)</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C₂S (%)</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C₃A (%)</td>
<td>8 max</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C₄AF (%)</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C₃S + 4.75C₂S (%)</td>
<td>100 max</td>
<td>93.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes
* Values in the limit / result columns mean Not Applicable
* It is permissible to exceed the specification limit provided that ASTM C150 mortar bar expansion does not exceed 0.020% at 14 days.
* Adjusted per Annex A1.3 of ASTM C150 and AASHTO M85.
* Test result represents most recent value and is provided for information only. Analysis of heat of hydration has been carried out by CTL Group, Skokie, IL. This data may have been reported on previous mill certificates.

Sito 33
1/27/2015
Grid 331

Additional Data

Inorganic Processing Addition Data

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>-</td>
</tr>
<tr>
<td>Amount (%)</td>
<td>-</td>
</tr>
<tr>
<td>SiO₂ (%)</td>
<td>-</td>
</tr>
<tr>
<td>Al₂O₃ (%)</td>
<td>-</td>
</tr>
<tr>
<td>Fe₂O₃ (%)</td>
<td>-</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>-</td>
</tr>
<tr>
<td>SO₃ (%)</td>
<td>-</td>
</tr>
</tbody>
</table>

Base Cement Phase Composition

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S (%)</td>
<td>31</td>
</tr>
<tr>
<td>C₂S (%)</td>
<td>12</td>
</tr>
<tr>
<td>C₃A (%)</td>
<td>7</td>
</tr>
<tr>
<td>C₄AF (%)</td>
<td>10</td>
</tr>
</tbody>
</table>

By [Redacted], Quality Manager
# Material Certification Report

**Material:** Portland Cement  
**Type:** II-V  
**Test Period:** 01-Dec-2015 to 31-Dec-2015

## Certification

This Holcim cement meets the specifications of ASTM C150 for Type II-V cement.

## General Information

- **Supplier:**
- **Address:**
- **Telephone:**
- **Date Issued:** 09-Jan-2016
- **Source Location:**
- **Contact:**

The following information is based on average test data during the test period. The data is typical of cement shipped by Holcim; individual shipments may vary.

## Tests Data on ASTM Standard Requirements

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Limit</th>
<th>Result</th>
<th>Physical</th>
<th>Limit</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SiO_2$ (%)</td>
<td>20.2</td>
<td>4.0</td>
<td>Air Content (%)</td>
<td>12 max</td>
<td>7</td>
</tr>
<tr>
<td>$Al_2O_3$ (%)</td>
<td>3.5</td>
<td>6.0</td>
<td>Blaine Fineness ($m^2/kg$)</td>
<td>290 min</td>
<td>400</td>
</tr>
<tr>
<td>$Fe_2O_3$ (%)</td>
<td>3.0</td>
<td>6.0</td>
<td>Autoclave Expansion (%) (C151)</td>
<td>0.80 max</td>
<td>0.01</td>
</tr>
<tr>
<td>$CaO$ (%)</td>
<td>63.3</td>
<td>3.0</td>
<td>Compressive Strength MPa (psi):</td>
<td>3 days</td>
<td>10.0 (1450) min 30.8 (4470)</td>
</tr>
<tr>
<td>$MgO$ (%)</td>
<td>2.6</td>
<td>3.0</td>
<td></td>
<td>7 days</td>
<td>17.0 (2470) min 37.1 (5380)</td>
</tr>
<tr>
<td>$SO_3$ (%)</td>
<td>3.0</td>
<td>0.75</td>
<td>Insoluble Residue (%)</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Loss on Ignition (%)</td>
<td>3.0</td>
<td>0.75</td>
<td>Autoclave Expansion (%) (C151)</td>
<td>0.80 max</td>
<td>0.01</td>
</tr>
<tr>
<td>Inorganic Processing Addition (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>Mortar Bar Expansion (%) (C1038)</td>
<td>-</td>
<td>0.014</td>
</tr>
<tr>
<td>Potential Phase Compositions$^5$:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_2S$ (%)</td>
<td>61</td>
<td>5.0</td>
<td>Initial Vicat (minutes)</td>
<td>45-375</td>
<td>124</td>
</tr>
<tr>
<td>$C_3S$ (%)</td>
<td>10</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_4AF$ (%)</td>
<td>5</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_2AF$ (%)</td>
<td>9</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_3S + 4.75C_2A$ (%)</td>
<td>84.8</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Tests Data on ASTM Optional Requirements

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Limit</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Alkalis (%)</td>
<td>0.60 max</td>
<td>0.55</td>
</tr>
<tr>
<td>Heat of Hydration: KJ/kg (cal/g)$^5$</td>
<td>7 Days (for informational purposes)</td>
<td>-</td>
</tr>
</tbody>
</table>

## Notes

$^a$ Dashes in the limit / result columns mean Not Applicable.  
$^b$ It is permissible to exceed the specification limit provided that ASTM C1038 Mortar Bar Expansion does not exceed 0.020 % at 14 days.  
$^5$ Adjusted per Annex A1.6 of ASTM C150 and AASHTO M085.  
$^6$ Test result represents most recent value and is provided for information only. Analysis of Heat of Hydration has been carried out by CTLGroup, Skokie, IL.  
$^7$ This data may have been reported on previous mill certificates.

## Additional Data

### Inorganic Processing Addition Data

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>-</td>
</tr>
<tr>
<td>Amount (%)</td>
<td>-</td>
</tr>
<tr>
<td>$SiO_2$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$Al_2O_3$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$Fe_2O_3$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$CaO$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$SO_3$ (%)</td>
<td>-</td>
</tr>
</tbody>
</table>

### Base Cement Phase Composition

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>-</td>
</tr>
<tr>
<td>Amount (%)</td>
<td>-</td>
</tr>
<tr>
<td>$SiO_2$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$Al_2O_3$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$Fe_2O_3$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$CaO$ (%)</td>
<td>-</td>
</tr>
<tr>
<td>$SO_3$ (%)</td>
<td>-</td>
</tr>
</tbody>
</table>
Material Certification Report

Type: III, V To: 31-Dec-2015

Certification

This Holcim cement meets the specifications of ASTM C150 for Type III, V cement.

General Information

Supplier: Source Location: 
Address: 
Telephone: 08-Jan-2016 Contact: 
Date Issued: 08-Jan-2016

The following information is based on average test data during the test period.
The data is typical of cement shipped by Holcim; individual shipments may vary.

Tests Data on ASTM Standard Requirements

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Limit&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>-</td>
</tr>
<tr>
<td>MgO (%)</td>
<td>6.0 max</td>
</tr>
<tr>
<td>SO&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>3.5 max&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Loss on Ignition (%)</td>
<td>3.0 max</td>
</tr>
<tr>
<td>Insoluble Residue (%)</td>
<td>0.75 max</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>Limestone (%)</td>
<td>5.0 max</td>
</tr>
<tr>
<td>CaCO&lt;sub&gt;3&lt;/sub&gt; in Limestone (%)</td>
<td>70 min</td>
</tr>
<tr>
<td>Inorganic Processing Addition (%)</td>
<td>5.0 max</td>
</tr>
<tr>
<td>Potential Phase Compositions&lt;sup&gt;c&lt;/sup&gt;:</td>
<td></td>
</tr>
<tr>
<td>C&lt;sub&gt;2&lt;/sub&gt;S (%)</td>
<td>-</td>
</tr>
<tr>
<td>C&lt;sub&gt;3&lt;/sub&gt;S (%)</td>
<td>-</td>
</tr>
<tr>
<td>C&lt;sub&gt;3&lt;/sub&gt;A (%)</td>
<td>15 max</td>
</tr>
<tr>
<td>C&lt;sub&gt;4&lt;/sub&gt;AF (%)</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Limit&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Content (%)</td>
<td>12 max</td>
<td>8</td>
</tr>
<tr>
<td>Blaine Fineness (m&lt;sup&gt;2&lt;/sup&gt;/kg)</td>
<td>-</td>
<td>517</td>
</tr>
<tr>
<td>Autoclave Expansion (%) (C151)</td>
<td>0.60 max</td>
<td>0.01</td>
</tr>
<tr>
<td>Compressive Strength MPa (psi):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>12.0 (1740) min</td>
<td>25.5 (3690)</td>
</tr>
<tr>
<td>3 days</td>
<td>24.0 (3480) min</td>
<td>33.5 (4800)</td>
</tr>
<tr>
<td>7 days</td>
<td>15.0 (2180) min</td>
<td>41.9 (6070)</td>
</tr>
<tr>
<td>Initial Vicat (minutes)</td>
<td>45-375</td>
<td>84</td>
</tr>
<tr>
<td>Mortar Bar Expansion (%) (C1038)</td>
<td>-</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Tests Data on ASTM Optional Requirements

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Limit&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Equivalent Alkalis (%)</td>
<td>0.60 max</td>
</tr>
<tr>
<td>False Set (%)</td>
<td>50 min</td>
</tr>
</tbody>
</table>

Notes
<sup>a</sup> Dashes in the limit / result columns mean Not Applicable.
<sup>b</sup> It is permissible to exceed the specification limit provided that ASTM C1038 Mortar Bar Expansion does not exceed 0.020 % at 14 days.
<sup>c</sup> Adjusted per Annex A1.6 of ASTM C150 and AASHTO M85.
This data may have been reported on previous mill certificates.

Additional Data

Inorganic Processing Addition Data

<table>
<thead>
<tr>
<th>Item</th>
<th>Result&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td></td>
</tr>
<tr>
<td>Amount (%)</td>
<td></td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>-</td>
</tr>
<tr>
<td>SO&lt;sub&gt;3&lt;/sub&gt; (%)</td>
<td>-</td>
</tr>
</tbody>
</table>

Base Cement Phase Composition

<table>
<thead>
<tr>
<th>Item</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&lt;sub&gt;2&lt;/sub&gt;S (%)</td>
<td>-</td>
</tr>
<tr>
<td>C&lt;sub&gt;2&lt;/sub&gt;S (%)</td>
<td>-</td>
</tr>
<tr>
<td>C&lt;sub&gt;3&lt;/sub&gt;A (%)</td>
<td>-</td>
</tr>
<tr>
<td>C&lt;sub&gt;4&lt;/sub&gt;AF (%)</td>
<td>-</td>
</tr>
</tbody>
</table>
**CHEMICAL DATA**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIMIT</th>
<th>RESULT</th>
<th>ITEM</th>
<th>LIMIT</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Dioxide (SiO₂) %</td>
<td>***</td>
<td>19.36</td>
<td>% Air Content</td>
<td></td>
<td>8.60</td>
</tr>
<tr>
<td>Aluminum Oxide (Al₂O₃) %</td>
<td>***</td>
<td>5.37</td>
<td>Blaine (cm²/g)</td>
<td>&gt;=2800</td>
<td>4990</td>
</tr>
<tr>
<td>Ferric Oxide (Fe₂O₃) %</td>
<td>***</td>
<td>2.73</td>
<td>% Pass 325 Mesh</td>
<td>***</td>
<td>99.23</td>
</tr>
<tr>
<td>Calcium Oxide (CaO) %</td>
<td>***</td>
<td>61.80</td>
<td>14 day C1038 Expansion %</td>
<td>&lt;=-0.020%</td>
<td>0.001</td>
</tr>
<tr>
<td>Magnesium Oxide (MgO) %</td>
<td>&lt;=6.00</td>
<td>2.66</td>
<td>% Autoclave Expansion %</td>
<td>&lt;=0.80</td>
<td>0.08</td>
</tr>
<tr>
<td>Sulfur Trioxide (SO₃) %</td>
<td>&lt;=3.5*</td>
<td>3.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss on Ignition (LOI) %</td>
<td>&lt;=3.0</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Oxide (Na₂O) %</td>
<td>***</td>
<td>0.24</td>
<td>Compressive Strength</td>
<td>***</td>
<td>3370</td>
</tr>
<tr>
<td>Potassium Oxide (K₂O) %</td>
<td>***</td>
<td>0.96</td>
<td></td>
<td>***</td>
<td>4260</td>
</tr>
<tr>
<td>Total Alkali %</td>
<td>***</td>
<td>0.87</td>
<td>1 day</td>
<td>***</td>
<td>5110</td>
</tr>
<tr>
<td>Insoluble Residue %</td>
<td>&lt;=0.75</td>
<td>0.09</td>
<td>7 day</td>
<td>***</td>
<td>5745</td>
</tr>
<tr>
<td>Limestone</td>
<td>&lt;=5.0</td>
<td>62.60</td>
<td>28 day</td>
<td>Prev Month</td>
<td>5745</td>
</tr>
<tr>
<td>L Color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential Compounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₃S</td>
<td>***</td>
<td>53.20</td>
<td>Time of set</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₂S</td>
<td>***</td>
<td>15.40</td>
<td>Vicat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₃A</td>
<td>***</td>
<td>8.60</td>
<td>Initial (minute)</td>
<td>45&gt;X&lt;375</td>
<td>60</td>
</tr>
<tr>
<td>C₄AF</td>
<td>***</td>
<td>8.30</td>
<td>PFS</td>
<td></td>
<td>77.00</td>
</tr>
</tbody>
</table>

*In cases where cement properties can be improved by higher SO₃ content, SO₃ may exceed 4.5% provided that expansion in water at 14 days does not exceed 0.020% as demonstrated by test method C1038.

This cement has been tested and is certified to meet the requirements of the latest version of ASTM C-150. This cement is PENNDOT, DELDOT, NYSDOT and NJDOT certified.
Temperature Control of Concrete Mixes

Note: Of the ingredients used for making concrete, mixing water is the easiest and most practical to heat. The weight of aggregates and cement in the average mix is much greater than the weight of water. However, water can store five (5) times as much heat as can solid materials of the same weight. The average specific heat [heat units required to change the temperature of one (1) lb (kg) of material one (1) °F (K)] of the solid materials in concrete (cement and aggregates) may be assumed as 0.22 Btu/[lb·°F] (920 J/[kg·K]) compared to 1.0 (4,200) for water.

Determine by calculation combined temperature of coarse aggregate, sand and cement using batch weights, observed temperatures of the mix components and their specific heat.

Example:

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
<th>Specific Heat</th>
<th>Water Equivalent (A x B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>lb/yd³</td>
<td>Btu/[lb·°F]</td>
<td>(MJ/[m³·K])</td>
</tr>
<tr>
<td>Aggregates</td>
<td>0.22</td>
<td>920</td>
<td>0.22</td>
</tr>
<tr>
<td>Cement</td>
<td>0.22</td>
<td>920</td>
<td>0.22</td>
</tr>
<tr>
<td>Aggregates</td>
<td>829.4</td>
<td>2.06</td>
<td>2.06</td>
</tr>
</tbody>
</table>

The combined temperature of the aggregate and cement will be

\[
E = \frac{44,550}{829.4} = 54° F
\]

Concrete should have a temperature between 50 °F (10 °C) and 90 °F (32.2 °C) when placed in the forms.

How to use chart

1. Place rule on the blue thermometer at the desired temperature of the concrete.
2. Pivot rule at this point and swing the left end of the rule to the calculated combined temperature of the aggregates and cement
3. The temperature of the mixing water is read on the right, at the point where the rule crosses the thermometer.

Note: (a) If sand is surface dry, use the solid line on the body of the blue thermometer as pivot point.
(b) If there is free moisture in the sand, use dotted line.
Explanation and Example

At the bottom of the Temperature Chart on the other side of this sheet, you will read instructions on how to use the chart.

The objective is to determine what temperature you need to preheat the water to in order to achieve a specific concrete temperature, when you know the combined temperature of the cement and aggregates in the mixer. You will see that there are 5 blue columns for concrete temperatures – the one you select will depend on how much mix water you have per cubic meter. To determine the combined temperature of the cement and aggregates in the mixer, simply mix those 2 ingredients for about a minute, then point an infrared thermometer into the mixer, and note the reading.

For example, let’s say we want to achieve a concrete temperature of 50°F, we have 30 gallons per cubic yard of mix water, the combined temperature of the cement and aggregates is 32°F, and we want to know what the preheated temperature of the water needs to be.

1. Place a straight edge, such as a ruler, at 50°F on the concrete temperature – that is, the blue column that shows 30 gallons per cubic yard at the bottom.
2. Pivot the end of the ruler so that it is at 32°F on the cement and aggregate thermometer on the left side of the chart.
3. Holding the ruler on 32°F on the thermometer on the left, and at 50°F on the blue thermometer in the middle of the chart, read the required water preheat temperature on the water thermometer on the right side of the chart. You will see that you need to preheat the water to 134°F in order to achieve a concrete temperature of 50°F.

Caution: Note that the Fahrenheit readings are on the right side of the cement/aggregate and concrete temperature thermometers, but on the left side of the water thermometer.