Definitions

• Water / Cementitious Ratio (w/c)
• Specific Gravity (SG)
• Aggregate Moisture
Water / Cement(itious) Ratio

• It’s a calculation:
  - w/c ~ lbs. of water / lbs. of cement
  - w/c_m ~ lbs. of water / lbs. of cementitious

Often when w/c is discussed its really w/c_m that is intended as the reference

\[
\frac{45 \text{ lbs of water}}{100 \text{ lbs of cement}} = 0.45 \text{ expressed as decimal}
\]

Water needs to be drinkable or meet ASTM 1602
Specific Gravity

What is Specific Gravity?

• Specific Gravity
  ▪ The relative density of a material compared to water
  ▪ The ratio of a material’s weight to the weight of an equal volume of water

• Bulk specific gravity (SSD):
  ▪ Used to determine the “solid volume” (absolute volume) of a material going into concrete
  ▪ It is determined by submerging the material in water for 24 hours in order to fill any permeable voids
Specific Gravity

Stone: Specific Gravity = 2.70

Water: Specific Gravity = 1.00

Same Volume, but 2.70 Times More Mass

Cement – 3.15
Steel – 7.85
Aggregate Moisture

- Bone Dry or Oven Dry
- Air Dry
- Saturated and Surface Dry
- Moist

Absorbed moisture (absorption)

SSD (ideal)

Free moisture (moisture content)

Add Water

Subtract Water
Review of Raw Materials

- Portland Cement
- Fly Ash
- Slag Cement
- Water
- Aggregates
Portland Cement

Why is it called “Portland Cement”?

Named after Portland Stone found on the Isle of Portland, in Dorset, England
Cement Compounds

- **Tricalcium Silicate – C₃S**
  - Lots of Heat Production and Early Age Strength
  - Controls Initial and Final Setting

- **Dicalcium Silicate – C₂S**
  - Later Age Strength and Less Heat Production

- **Tricalcium Aluminate – C₃A**
  - Lots of Heat Production
  - Contributes to very early Age Strength
  - Controls Sulfate Attack Resistance

- **Tetracalcium Aluminoferrite – C₄AF**
  - Some Heat Generation but Contributes Little Strength
  - Responsible for Grey Color
Cement Compounds

- **Tricalcium Silicate – C$_3$S**
  - Lots of Heat Production and Early Age Strength
  - Controls Initial and Final Setting
- **Dicalcium Silicate – C$_2$S**
  - Later Age Strength and Less Heat Production
- **Tricalcium Aluminate – C$_3$A**
  - Lots of Heat Production
  - Contributes to very early Age Strength
  - Controls Sulfate Attack Resistance
- **Tetracalcium Aluminoferrite – C$_4$AF**
  - Some Heat Generation but Contributes Little Strength
  - Responsible for Grey Color
<table>
<thead>
<tr>
<th>Type of portland cement</th>
<th>Potential Compound Composition, %</th>
<th>Blaine fineness m²/kg</th>
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IV: NO LONGER AVAILABLE
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<th>CHEMICAL REQUIREMENTS</th>
<th>Spec. Limit</th>
<th>TYPE I Low Alkali</th>
<th>TYPE II Low Alkali</th>
<th>TEST RESULTS</th>
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<td>(ASTM C-114) Silicon Dioxide (SiO2), %</td>
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<td>Heat Index, C3S + (4.75 C3A)</td>
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<td>(ASTM C-204) Blaine Fineness, m2/kg</td>
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<td>(ASTM C-191) Time of Setting (Vicat)</td>
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<td>Initial Set, mins</td>
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<td>Final Set, mins</td>
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<td>(ASTM C-266) Time of Setting (Gilmore)</td>
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<td>(ASTM C-185) Air Content, %</td>
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<td>(ASTM C-151) Autoclave Expansion, %</td>
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<td>(ASTM C-109) Compressive Strength</td>
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<td>3-Day, psi</td>
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<td>7-Day, psi</td>
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<td>(Previous) 28-Day, psi</td>
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<td>(ASTM C-186) Heat of Hydration (7-Day), cal/g</td>
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<td>Calcium Oxide (CaO) - Percent</td>
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<td>Magnesium Oxide (MgO) - Percent</td>
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<td>Loss on Ignition - Percent</td>
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<td>Carbon dioxide (CO2) - Percent</td>
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<td>Limestone content - Percent</td>
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<td>CaCO3 in Limestone - Percent</td>
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<td>Tricalcium Silicate (C3S) - Percent</td>
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<td>Dicalcium Silicate (C2S) - Percent</td>
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<td>Tricalcium Aluminate (C3A) - Percent</td>
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<td>Tetracalcium Alumi-oxide (C4AF) - Percent</td>
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<td>C4AF + 2 (C3A) or C4AF + C2F - Percent</td>
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<tr>
<td>Alkalies (Sodium Oxide Equivalent) - Percent</td>
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<td>STANDARD PHYSICAL REQUIREMENTS</td>
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<td>Specific Surface, Blaine, m2/kg</td>
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<td>- 325 Mesh - Percent</td>
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<td>Compressive Strengths, psi (MPa) (C109 cubes)</td>
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<td>7 DAYS</td>
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<tr>
<td>Time of Setting (Vicat)</td>
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<td>Initial, minutes</td>
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<tr>
<td>Final, minutes</td>
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<tr>
<td>False Set - Percent</td>
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<tr>
<td>Air Content of Mortar - Percent</td>
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<td>Autoclave Expansion - Percent</td>
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<td>Mortar Bar Expansion (ASTM C-1038) Only for T-V - Percent</td>
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## Cement comparison

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<tr>
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<td>Initial Vicat</td>
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<tr>
<td>Final Vicat</td>
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<td>280</td>
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</table>
Cement Reaction

Primary cement reaction (fast):
\[ \text{C}_3\text{S} \ (\text{and } \text{C}_2\text{S}) + \text{water} = \text{C-S-H gel} \]
Byproduct from hydration = Calcium Hydroxide

Pozzolanic reaction (slow):
Fly Ash + Calcium Hydroxide = C-S-H gel
Fly Ash

• Byproduct from the burning of coal used in power plants

• Class F
  ▪ Produced from burning anthracite or bituminous coal
  ▪ Older coal, eastern & west coast
  ▪ Pozzolanic (no cementing properties, reacts to cement hydration byproducts only)

• Class C
  ▪ Produced from burning subbituminous coal
  ▪ Younger coal, western
  ▪ Cementing and pozzolanic properties
Fly Ash

- Classes are usually grouped by
  - Sum of Silica, Alumina, and Iron oxides
    - > 50% - Class C Fly Ash
    - > 70% - Class F Fly Ash
  - Calcium Content (CaO)
    - < 20% typically Class F Fly Ash
    - > 20% typically Class C Fly Ash
Fly Ash

Advantages
- Improve workability
- Lower mix cost
- Reduce Heat
- Lower permeability
- Improve Durability
- Mitigates ASR and DEF (Class F only)

Disadvantages
- Low Early-Age Strength
- Increase set time
- Effect Air entrainment (Class F)
Slag Cement

- Byproduct from the iron manufacturing process

- **ASTM C 989 Standard Specification for Slag Cement for Use in Concrete and Mortars** (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%)

*Slag Cement is a hydraulic cement*
Ground Granulated Blast-Furnace Slag

Ball Mill

Slag Cement

www.concrete-pipe.org
Slag - Features and Benefits

• Benefits for Hardened Concrete
  ▪ Later age strength
  ▪ Increased flexural strength
  ▪ Lighter, brighter color (substitute for white cement)
  ▪ Increased ability to reflect solar heat
  ▪ Reduced permeability and increased durability
  ▪ Increased resistance to alkali silica reaction
    ▪ 25% to 70%
  ▪ Increased sulfate resistance (low alumina slag)
    ▪ 40% to 70%
Slag - Cautions

- As cement replacement rates increase, freeze/thaw durability can be reduced (on flat work).
- Sensitive to cold weather, below 40 deg F (set time and early strength).
- As levels of unoxidized sulfide sulfur increase, a temporary greening of the hardened concrete may occur.
Water

• Use potable water for concrete
• Non-potable water contains deleterious substances
  ▪ Oils
  ▪ Acids
  ▪ Alkalis
  ▪ Salts
• These items have negative effects on concrete strength
How Much Water?

• Hydration water
  ▪ About 0.24 lb of water to hydrate 1 lb of cement
  ▪ This water takes part in the hydration reactions

• Water of Convenience
  ▪ Water for mixing, placing and finishing
  ▪ This water dictates the pore structure of the cement paste
**W/C Ratio**

\[ \text{W/C} = \frac{\text{Weight of Water}}{\text{Weight of Cementitious Material}} \]

**Graph showing hardened concrete characteristics**

- **Strength** (red line) decreases as W/C ratio increases.
- **Porosity** (green line) increases as W/C ratio increases.
W/C Ratio

• Water/Cement ratio impacts concrete strength and durability
• Low w/c ratio = strong & durable concrete
• Arbitrarily adding water to the mix will have a negative effect on strength and durability
Adding 1 gal of water / yd$^3$ of concrete

- Increases slump 1”
- Decreases compressive strength by 5%
- Wastes the effect of 24 lbs/yd$^3$ of cement
- Increases shrinkage by 10%
- Increases permeability by up to 50%
- Decreases freeze-thaw durability by 20%
- Decreases resistance to deicing salts and lowers quality in many other ways
Aggregates

• Fine
  ▪ Consists of natural sand, manufactured sand or crushed stone
  ▪ <3/8”
  ▪ Fine aggregate will pass the #4 sieve
• Coarse
  ▪ Natural or crushed stone
  ▪ 3/8” to 1 ½” (or more)
  ▪ Coarse aggregate is larger than the #4 sieve
Particle Shape

• Impacts friction within mixture
• Impacts voids content
• Influences water demand
• Influences paste / aggregate bond
• Impacts strength
Particle Shape

(a) Rounded

(d) Flaky

(c) Angular

(e) Elongate

(f) Elongate and Flaky
Particle Shape

- Rounded particles
  - Decrease friction (improve workability)
  - Decrease water demand
  - Enhance finishing
- Angular/Crushed particles
  - Increase water demand, improve strength due to paste aggregate bond
  - Higher stability
  - Resistance to volumetric changes under loads
Particle Shape

• Flat and/or elongated particles can
  ▪ Reduce workability
  ▪ Interfere with consolidation
  ▪ Reduce mass stability due to lower strength
  ▪ Recommended limit 15% (3:1 ratio)
Cleanliness

- Clay or other very fine materials (-200 mesh)
  - Limit is 3% in fine aggregate and 1% in coarse aggregate
  - Can negatively affect strength & admixture effectiveness
Cleanliness

• Organic matter such as loam, silt, bark, leaves, etc.
  ▪ Can negatively affect strength & admixture effectiveness

• Soft friable particles
  ▪ Limit is 3% in fine aggregate or 1% in coarse aggregate
  ▪ Can cause pop-outs or staining in finished units
Voids

Which one has the greatest void content?

1-inch diameter Spherical aggregate
0.858

1/2-inch diameter Spherical aggregate
0.858

1/4-inch diameter Spherical aggregate
0.858
Voids

Sand

Stone

Well Graded Blend
Voids

- Reduce core compressive and tensile strength
- Lower D-load results
- Increased Absorption
- Lower durability
- Higher permeability
- Increased paste requirements
- Increase cost
Gradation

- Particle size distribution influences the workability, roughness and texture of mixes
- Well-graded aggregate structure reduces paste requirement
- Poorly-graded aggregate structure will result in voids that will have a negative effect on the mix
Gradation

- Poor/Gap-Graded
  - More paste volume needed
  - Higher water demand
- Well Graded
  - Increase packing density
  - Reduce paste content
  - Improve workability and finishability
  - Reduce permeability
Gap Graded vs. Well Graded
Fine Aggregate Gradation

- Fine Aggregate Gradation can affect:
  - Water Demand, Bleeding, Workability, Finishability, and Durability
- Excessive amount of fines increases the water demand
- Insufficient amount of fines results in excessive bleeding and difficulty in finishing
- Excessive amount of material passing the No. 200 sieve can result in:
  - Reduced Strength, Poor Durability, Poor Abrasion Resistance, increased shrinkage
Fineness Modulus

- Indicates how fine or coarse the material is, lower FM = finer aggregate
- Finer material particles have larger surface area, more water/cement is required to coat the particles
- Typical range for sand 2.3 – 2.9
- FM lower than 2.5 can reduce strength
Gradation

1x1 Square  
6 Sides  
1 Cube  
1x1x6x1=  
6 Area

1/2 x 1/2 Square  
6 Sides  
8 Cube  
1/2 x 1/2 x 6 x 8 =  
12 Area

1/4 x 1/4 Square  
6 Sides  
64 Cube  
1/4 x 1/4 x 6 x 64  
= 24 Area
# Sieve Analysis

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</tr>
<tr>
<td>#16</td>
<td>4.0</td>
<td>3.0</td>
<td>69.0</td>
</tr>
<tr>
<td>#30</td>
<td>1.0</td>
<td>1.0</td>
<td>42.0</td>
</tr>
<tr>
<td>#50</td>
<td>0.0</td>
<td>1.0</td>
<td>18.0</td>
</tr>
<tr>
<td>#100</td>
<td>0.0</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>#200</td>
<td>0.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**AGGREGATE BLENDING**

---

[Graphs showing the percentage passing and retained for different sieve sizes.]
Mix Design

- Mix design is the process of determining required and specifiable characteristics of a concrete mixture.
- The characteristics can be based on fresh and/or hardened concrete properties, and inclusion, exclusion or limits of specific ingredients.
- Mix design requirements are based on intended use, environment, etc.
Mix Proportioning

- Mix proportioning is the process of determining the quantities of concrete ingredients that meet the mix design criteria.

- Cement?
- SCM’s?
- Water?
- Admix?
- Fine Aggregate?
- Coarse Aggregate?
Mix Proportioning

• The primary considerations include:
  ▪ Meeting or exceeding specifications
  ▪ Availability of raw materials
  ▪ Acceptable workability of the mix
  ▪ Durability, strength & uniform appearance of the finished concrete
  ▪ Economy
Mix Proportioning

• There are number of ways to proportion mixes:
  ▪ Water-cement ratio method
  ▪ Weight method
  ▪ Absolute volume method (ACI 211.1)
  ▪ Field experience (statistical data)

• We will focus on the Absolute Volume Method
Mix Proportioning

Absolute Volume Method

• Required strength
• w/c ratio
• Air content
• Slump
• Water content
• Cementitious
• Coarse aggregate
• Admixtures
• Fine aggregate
Required Strength

- Strength requirements are based on specifications and design assumptions
- Variability exists in both materials and testing procedures

Example:
5000 psi at 28 days
W/C Ratio

- w/c should be based on strength and durability requirements (specs)
- Check relationship between strength & w/c
- Durability requirements based on various exposure conditions
- Most severe case governs

Example:
5000 psi at 28 days
w/c = 0.40
Compressive strength vs. w/c ratio
## Relationship between w/c ratio & strength

<table>
<thead>
<tr>
<th>Compressive strength at 28 days, psi</th>
<th>Water-cementitious materials ratio by mass</th>
<th>Non-air-entrained concrete</th>
<th>Air-entrained concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>7000</td>
<td>0.33</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6000</td>
<td>0.41</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>0.48</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>0.57</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>0.68</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>0.82</td>
<td>0.74</td>
<td></td>
</tr>
</tbody>
</table>
# Requirements for exposure conditions

<table>
<thead>
<tr>
<th>Exposure Condition</th>
<th>Max w/c ratio by mass</th>
<th>Min strength, f’c, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>No freeze-thaw, deicers, aggressive substances</td>
<td>Select for strength,</td>
<td>Select for structural requirements</td>
</tr>
<tr>
<td></td>
<td>workability, and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>finishing needs</td>
<td></td>
</tr>
<tr>
<td>Concrete with low permeability; exposed to water</td>
<td>0.50</td>
<td>4000</td>
</tr>
<tr>
<td>Concrete exposed to freezing and thawing in a moist condition or deicers</td>
<td>0.45</td>
<td>4500</td>
</tr>
<tr>
<td>For corrosion protection for reinforced concrete exposed to chlorides</td>
<td>0.40</td>
<td>5000</td>
</tr>
</tbody>
</table>
# Requirements for exposure to sulfates

<table>
<thead>
<tr>
<th>Sulfate exposure</th>
<th>Sulfate ((SO_4)) in soil, % by mass</th>
<th>Sulfate ((SO_4)) in water, ppm</th>
<th>Cement type</th>
<th>Max w/c ratio, by mass</th>
<th>Min strength, f’c, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>Less than 0.10</td>
<td>Less than 150</td>
<td>No special type required</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.10 to 0.20</td>
<td>150 to 1500</td>
<td>Type II</td>
<td>0.50</td>
<td>4000</td>
</tr>
<tr>
<td>Severe</td>
<td>0.20 to 2.00</td>
<td>1500 to 10,000</td>
<td>Type V</td>
<td>0.45</td>
<td>4500</td>
</tr>
<tr>
<td>Very severe</td>
<td>Over 2.00</td>
<td>Over 10,000</td>
<td>Type V</td>
<td>0.40</td>
<td>5000</td>
</tr>
</tbody>
</table>
Air Content

- Air entrained concrete target from exposure conditions & nominal maximum aggregate size
- For the example use 3/8” nominal aggregate & non air entrained concrete (3.0% air)

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Air content and aggregate size

![Graph showing the relationship between nominal maximum aggregate size and target air content. The graph includes lines for severe exposure (deicers), moderate exposure, mild exposure, and non-air-entrained concrete.](image)
Compressive Strength Vs % Air

Water content was reduced with increased air content to maintain a constant slump.
Slump

- Target workability in terms of slump is based on method of placement.

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
Workability requirements

Increased risk of segregation

Slump (mm)

- Plasticized (ACI 301)
- Pre-plasticized (ACI 301)
- Concrete floors (See ACI 302)
- General purpose concrete (SEE ACI 301)
- Pavement and slabs (ACI 211.1)
- Beams, reinforced walls and building columns (ACI 211.1)
- Plain and reinforced foundation & sub-structure walls, footings, and caissons (ACI 211.1)
- Mass concrete (ACI 211.1)
- Various slip formed applications
- "Zero Slump" or "No Slump" concrete

Increased risk of unworkable concrete

Slump (in.)
Water content

- Water content is influenced by:
  - Agg size, shape, texture
  - Slump
  - w/c ratio
  - Air content
  - Cementitious type
  - Cem content
  - Admixtures
  - Environmental conditions

- Even with drycast concrete there is a minimum water requirement based on the above

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
200 lbs water/yd³
# Water requirements for various slumps

<table>
<thead>
<tr>
<th>Slump, in.</th>
<th>Water, lbs/yd$^3$ of concrete for indicated size of aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3/8 in.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Non air entrained concrete</td>
<td></td>
</tr>
<tr>
<td>1 to 2</td>
<td>350</td>
</tr>
<tr>
<td>3 to 4</td>
<td>385</td>
</tr>
<tr>
<td>6 to 7</td>
<td>410</td>
</tr>
</tbody>
</table>

Above is based on crushed stone, water estimates can be reduced by 20 lbs for sub-angular stone, 35 lbs for some crushed particles and 45 lbs for rounded gravel.

Water can be reduced for various other factors including admixtures.

Correct slump should be verified by trial batches.
Cementitious content

- Cementitious materials content based on previously determined w/c ratio and water requirements
- Check specification limits for minimum content required
- Use 20% fly ash replacement by weight for the example

\[
\frac{200 \text{ lbs}}{0.40} = 500 \text{ lbs}
\]

500 lbs x 0.8 = 400 lbs

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
200 lbs water/yd^3
400 lbs cement/yd^3
100 lbs fly ash/yd^3
Cementitious content

What is the minimum cement content per yard specified by ASTM C76?

470 lbs/yd$^3$
Coarse Aggregate

• Aggregates are the least expensive and the most dimensionally stable ingredient
• Proper blending of aggregates will minimize the amount of paste required
• Aggregate proportions can be selected from blending worksheets or ACI 211.1 tables
• Use 45/55 agg blend for the example

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
200 lbs water/yd$^3$
400 lbs cement/yd$^3$
100 lbs fly ash/yd$^3$
# Bulk volume of coarse aggregate (ACI 211.1)

<table>
<thead>
<tr>
<th>Nominal max size of aggregate, (in.)</th>
<th>Fineness modulus of sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.40</td>
</tr>
<tr>
<td>3/8</td>
<td>0.50</td>
</tr>
<tr>
<td>1/2</td>
<td>0.59</td>
</tr>
<tr>
<td>3/4</td>
<td>0.66</td>
</tr>
<tr>
<td>1</td>
<td>0.71</td>
</tr>
<tr>
<td>1-1/2</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>0.78</td>
</tr>
<tr>
<td>3</td>
<td>0.82</td>
</tr>
<tr>
<td>6</td>
<td>0.87</td>
</tr>
</tbody>
</table>

*For calculations, use dry rodded bulk density

Example: density = 100 lb/ft³, stone per yard = 100 x 27 x 0.48 = 1296 lbs
Stone SG = 2.68, Abs. vol. of stone per yard = 1296/(2.68x62.4)= 7.750 ft³
Admixtures

• Admixtures should be dozed based on manufacturers recommendations and verified with trial batches & testing
• Use no admix for the example

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
200 lbs water/yd³
400 lbs cement/yd³
100 lbs fly ash/yd³
45/55 Agg Blend
Fine Aggregate

- Fine aggregate volume is determined by subtracting the absolute volumes of the known ingredients from 27 cu ft (1 yd$^3$)

Example:
5000 psi at 28 days
w/c = 0.40
3.0% air
Zero slump
200 lbs water/yd$^3$
400 lbs cement/yd$^3$
100 lbs fly ash/yd$^3$
45/55 Agg Blend
Mix Proportion Calculations

Given:
400 lbs of Cement, SG = 3.15
100 lbs of Fly Ash, SG = 2.50
200 lbs of Water, SG = 1.00
3% Air
45/55 Stone/Sand Blend
Stone SG = 2.68, Abs = 1.0%
Sand  SG = 2.62, Abs = 1.5%
Mix Proportion Calculations

• Calculate the absolute volume of each component

\[
\text{Absolute Volume} = \frac{\text{Weight of Material (lbs)}}{\text{S.G.} \times 62.4}
\]

Density of water = 62.4 lb/ft³
Mix Proportion Calculations

\[ V_{\text{cement}} = \frac{400}{3.15 \times 62.4} = 2.035 \text{ ft}^3 \]

\[ V_{\text{flyash}} = \frac{100}{2.50 \times 62.4} = 0.641 \text{ ft}^3 \]

\[ V_{\text{water}} = \frac{200}{1.00 \times 62.4} = 3.205 \text{ ft}^3 \]

\[ V_{\text{air}} = \frac{0.03 \times 27}{\phantom{27}} = 0.810 \text{ ft}^3 \]

\[ V_{\text{total}} = 6.691 \text{ ft}^3 \]
Mix Proportion Calculations

\[ V_{\text{aggregates}} = 27 - 6.691 = 20.309 \text{ ft}^3 \]

\[ V_{\text{stone}} = 0.45 \times 20.309 = 9.139 \text{ ft}^3 \]

\[ W_{\text{stone}} = 9.139 \times 2.68 \times 62.4 = 1528 \text{ lbs} \]

\[ V_{\text{sand}} = 0.55 \times 20.309 = 11.170 \text{ ft}^3 \]

\[ W_{\text{sand}} = 11.170 \times 2.62 \times 62.4 = 1826 \text{ lbs} \]
Mix Proportion Calculations

<table>
<thead>
<tr>
<th>Material</th>
<th>Lbs/yd³</th>
<th>S.G.</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>400</td>
<td>3.15</td>
<td>2.035</td>
</tr>
<tr>
<td>Fly ash</td>
<td>100</td>
<td>2.50</td>
<td>0.641</td>
</tr>
<tr>
<td>Water*</td>
<td>200</td>
<td>1.00</td>
<td>3.205</td>
</tr>
<tr>
<td>Stone*</td>
<td>1528</td>
<td>2.68</td>
<td>9.139</td>
</tr>
<tr>
<td>Sand*</td>
<td>1826</td>
<td>2.62</td>
<td>11.170</td>
</tr>
<tr>
<td>Air</td>
<td>3%</td>
<td>-</td>
<td>0.810</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4054</td>
<td></td>
<td>27.00</td>
</tr>
</tbody>
</table>

*Stone & sand moisture at SSD
Mix Proportioning

• These are the proportions for a trial batch
• Batch needs to be tested and adjusted
  ▪ Make adjustments for moisture
  ▪ Check workability, finishing, etc
  ▪ Make appropriate adjustments and rebatch
  ▪ If fresh properties are satisfactory, make samples for hardened properties
Mix Proportion Calculations

- Make the following adjustments to the trial batch
  - Adjust aggregate moisture, actual moisture of stone = 3%, sand = 4.5%
  - Eliminate fly ash and use 100% cement
Mix Proportion Calculations

Aggregate moisture adjustment

Free water in stone = 3% - 1% = 2%
Free water in sand = 4.5% - 1.5% = 3%

Weight of water in stone
0.02 x 1528 = 31 lbs

Weight of water in sand
0.03 x 1826 = 55 lbs

Batch water adjustment
31 + 55 = 86 lbs

<table>
<thead>
<tr>
<th></th>
<th>design</th>
<th>actual</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>400</td>
<td>400</td>
<td>lbs</td>
</tr>
<tr>
<td>Fly ash</td>
<td>100</td>
<td>100</td>
<td>lbs</td>
</tr>
<tr>
<td>Water</td>
<td>200</td>
<td>114</td>
<td>lbs</td>
</tr>
<tr>
<td>Stone*</td>
<td>1528</td>
<td>1559</td>
<td>lbs</td>
</tr>
<tr>
<td>Sand*</td>
<td>1826</td>
<td>1881</td>
<td>lbs</td>
</tr>
<tr>
<td>Total</td>
<td>4054</td>
<td>4054</td>
<td>Lbs/yd³</td>
</tr>
</tbody>
</table>
Mix Proportion Calculations

Eliminate fly ash from the mix

Keeping the volume constant, how many lbs of cement equals 100 lbs of fly ash?

\[ V_{\text{flyash}} = \frac{100}{2.50 \times 62.4} = 0.641 \text{ ft}^3 \]

\[ W_{\text{cement}} = 0.641 \times 3.15 \times 62.4 = 126 \text{ lbs} \]
Mix Proportion Calculations

- Two ways to eliminate 100 lbs of fly ash from the mix
  - Make a quick adjustment based on equal volumes
    - (eg. 100 lbs FA = 126 lbs cement)
  - Adjust quantities by weight and re-calculate aggregate proportions

<table>
<thead>
<tr>
<th></th>
<th>design</th>
<th>actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Fly ash</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Stone*</td>
<td>1528</td>
<td>1538</td>
</tr>
<tr>
<td>Sand*</td>
<td>1826</td>
<td>1838</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4054</td>
<td>4076</td>
</tr>
</tbody>
</table>

Lbs/yd$^3$
Mix Proportioning

If aggregate proportions were not adjusted and 100 lbs of cement was exchanged for 100 lbs of fly ash, what would happen to the total volume?

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>500</td>
<td>2.544</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>200</td>
<td>3.205</td>
</tr>
<tr>
<td>Stone*</td>
<td>1528</td>
<td>9.137</td>
</tr>
<tr>
<td>Sand*</td>
<td>1826</td>
<td>11.169</td>
</tr>
<tr>
<td>Air</td>
<td>3%</td>
<td>0.810</td>
</tr>
<tr>
<td>Total</td>
<td>4054</td>
<td>26.865</td>
</tr>
</tbody>
</table>

Under yield
Mix Proportioning

• Under yield situation happens when not enough of one or more raw material is batched, or material is substituted by weight and not corrected for volume

• Since volume stays constant, more raw materials are needed to fill that volume (more cement!)
Mix Proportioning

- Over yield situation happens when one or more raw material is batched over the required weight
- Batch occupies a larger volume, therefore less of the other raw materials are used in the product (less cement!)
- Could lead to lower strengths, workability issues, less cementitious material than allowed by specs
Mix Proportioning

• Substituting/Replacing raw materials (eg. Fly Ash for Cement) by weight will throw the yield off

• Raw material substitution/replacement must be done based on volume, not weight!

• Aggregate moisture will affect add-water, batch needs to be adjusted to maintain proper w/c and stone/sand ratio
QUESTIONS?