REINFORCED CONCRETE

Reinforced concrete (RC) is a structural composite made of plain concrete and reinforcing steel.

Advantages of RC as a Construction Material
- Resistance to action of water
  (Used almost exclusively in water-retaining and underground structures, bridge piers, etc.)
- Compressive loading applications
- Economy (unskilled labor)
- Architectural advantages (shell structures)

Disadvantages
- Reliability of material properties
- Labor-intensive
- Quality control

PLAIN CONCRETE

MATERIALS: cement, aggregate (fine and coarse), water, and admixtures

CEMENT: Portland cement (SG ~ 3.15; 94 lb/ft³ = 1 bag of cement)

Typical composition of Ordinary Portland cement

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricalcium silicate C₃S</td>
<td>55%</td>
</tr>
<tr>
<td>Dicalcium silicate C₂S</td>
<td>18%</td>
</tr>
<tr>
<td>Tricalcium aluminate C₃A</td>
<td>10%</td>
</tr>
<tr>
<td>Tetracalcium aluminoferrite C₄AF</td>
<td>8%</td>
</tr>
<tr>
<td>Calcium sulphate dihydrate CSH₂</td>
<td>6%</td>
</tr>
</tbody>
</table>

(Gypsum)

Type I: Normal, general use
Type II: Low heat of hydration
Type III: High early strength (attains 7-day strength in 3 days and 28-day strength in 7 days)
Type IV: Very low heat of hydration (for use in mass concrete applications)
Type V: Sulfate-resistant (for use in applications where member is exposed to sulfates such as sewer pipes)

Heat of Hydration: The chemical process during setting and hardening of concrete that result in the generation of heat

Expansive Cements

A major disadvantage of Portland cement is the volume contraction that takes place during drying which can lead to tensile cracking if the contraction is partly or fully restrained. Ordinary Portland cement experiences limited expansion during moist curing. But this can be modified and early expansion can be enhanced so as to offset the effects of drying shrinkage. Such cements are called “expansive” cements or “shrinkage-compensating” cements. Successful use of expansive cement depends on proper control of the expansion during hydration.
AGGREGATES
Occupy 70 – 80% of the volume of concrete and, therefore, plays an important role in defining the properties of concrete. Since aggregates contain some porosity, aggregates can absorb water. The presence of this water must be accounted for when estimating aggregate content in mix design.

FINE AGGREGATE (sand) – material that passes a #4 (0.25 inch) sieve
• Use well-graded sand free of organic impurities (conforming to ASTM standards)

COARSE AGGREGATE (stone)
• Aggregate larger than 0.25 in.
• Coarse aggregate comprises the bulk of plain concrete; hence the quality and strength of coarse aggregate contribute significantly to the quality and strength of the concrete.
• Normal-weight: 145 pcf concrete; Lightweight: 50 – 120 pcf concrete made from shale, slate, etc; Heavyweight aggregates: >200 pcf concrete made using iron ore, scrap steel, etc.

ADMIXTURES
• Superplasticizers: water-reducing chemicals which make mix more workable
• Air-entraining admixtures: improves workability, increases frost-resistance, produces lighter concrete
• Accelerating admixtures: reduce setting time, accelerate early-strength development
• Other chemical admixtures

PROPERTIES OF PLAIN CONCRETE
1) Compressive Strength: 28-day strength of 6 X 12 inch cylinders (ASTM C-39)
   Factors affecting compressive strength: aggregate strength, water-cement ratio, admixtures
2) Stress-Strain relationship

![Stress-Strain relationship graphs for normal and light weight concrete]

3) Modulus of Elasticity

\[ E_c = 33 w_c^{1.5} \sqrt{f'_c} \]

(Note: psi units)

4) Tensile strength

Tensile Strength: 10 – 20% of compressive strength

Split cylinder strength for direct tension:

\[ f_t = \frac{2P}{\pi L d} \]

\( (3\sqrt{f'_c} - 5\sqrt{f'_c} \) for normal weight concrete)\n
Modulus of rupture test for flexure:

\[ f_r = \frac{6M}{bh^2} \]

\( (6\sqrt{f'_c} - 8\sqrt{f'_c} \) for normal weight concrete)\n
(ACI requirement: \( f_r = 7.5 \sqrt{f'_c} \))

5) Workability (Slump test)

6) Shrinkage and Creep

![Graphs showing creep and shrinkage]

- Concrete stress vs. strain graph
- Graph showing creep and shrinkage over time
STRENGTH UNDER COMBINED STRESS

HIGH-STRENGTH CONCRETE

- Concretes with compressive strength > 6000 psi
- Mix Design
  - Lower water-cement ratio (< 0.40; achieved through use of superplasticizers)
  - Cement (>660 lb/yd³) though very high cement content make mix proportioning difficult
  - Use of mineral admixtures
    - Silica fume (5 – 10% by weight of cement content)
    - Fly ash (15 – 30%)
  - Fly ash reduces water demand and requires less superplasticizers
  - Silica fume generally produces higher strength cement for same % cement replacement but requires more superplasticizers
- Coarse Aggregates – quality
- Fine aggregate (coarser sands with higher fineness modulus > 3.0)
- Properties
  - \( E_c = (40000\sqrt{f'_c} + 10^6)(w_c/145)^{1.5} \)
  - Other properties such as modulus of rupture, tensile strength, etc. also affected
CONCRETE CONSTRUCTION PRACTICES
- PART 3 ➔ Chapters 4 – 6 (ACI Building Code)

- Batching and Mixing
- Transporting Concrete
- Placing
- Curing

MIX-DESIGN

Given the variability in material properties, particularly aggregates, it is unrealistic to develop a mix-design procedure that consistently provides the required strength of concrete. Concrete production facilities typically maintain statistical information on field data and corresponding mix designs (as required by ACI-318).

Given below are approximate data that can be used to develop a preliminary mix-design.
Assuming normal weight concrete using 3/8 – 1/2 inch aggregate and sand with a fineness modulus of 2.80
- Required water = 375 lb/yd³
- Water-cement ratio

<table>
<thead>
<tr>
<th>Compressive strength</th>
<th>W/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 psi</td>
<td>0.68</td>
</tr>
<tr>
<td>4000 psi</td>
<td>0.57</td>
</tr>
<tr>
<td>5000 psi</td>
<td>0.48</td>
</tr>
<tr>
<td>6000 psi</td>
<td>0.41</td>
</tr>
</tbody>
</table>
- Approximate concrete weight: 3900 lb/yd³
- Volume of coarse aggregate per unit volume of concrete: 0.50
Note: coarse aggregate in normal-weight concrete typically weighs about 100 pcf

YIELD OF A MIX

The “yield” of a mix is the volume of concrete produced from one sack of cement. In determining the yield, it is usually assumed that there are no voids in the mix.

The “cement factor” of a mix is the number of bags of cement required to produce 1 cubic yard of concrete.

The following units of conversion will aid in determining the “yield” and “cement factor”
- 1 sack of cement = 94 lbs (1 ft³ by volume)
- 1 gallon of water = 8.34 lbs
- 1 ft³ of water = 7.48 gallons (62.4 lbs)

Typical material properties:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>Bulk Density</th>
<th>Solid Density (lb/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.1</td>
<td>94</td>
<td>193 (3.1x62.4)</td>
</tr>
<tr>
<td>Sand</td>
<td>2.6</td>
<td>100</td>
<td>162 (2.6x62.4)</td>
</tr>
<tr>
<td>Stone</td>
<td>2.6</td>
<td>95</td>
<td>162 (2.6x62.4)</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>62.4</td>
<td>62.4</td>
</tr>
</tbody>
</table>

Bulk density = Total weight (incl. contained water and voids)/Bulk volume
Solid density = Weight of solid/Solid volume = Specific Gravity x Density of water
REINFORCING STEEL
- PART 3 ➔ Chapter 7 (ACI Building Code)

- Deformed bars
  - Grade
  - Standard bar sizes (Table A1 in Appendix – text book)

- Properties of typical steel reinforcing bars
  - Young’s modulus
  - Yield strength
  - Ultimate strength
- Ductility (ultimate strain of high strength bars)