Fundamentals of Concrete

Presented by
Rusty Boicourt, P.G.
NDE & Materials Specialist
Materials Testing & Inspection
Concrete History

Named after quarry stone from the Isle of Portland in Britain.

First used by Joseph Aspdin from Leeds, England in 1824.

Other forms used throughout antiquity.
Pantheon, Rome
built by Emperor Hadrian ~126 AD
Stabiae Baths, Pompeii
built 1st Century
Temple of Mercury, Baiae
built ~19 BC
Glossary of Terms

Components
W/cm ratio
Admixtures
Pozzolans
Workability
Consolidation
Hydration

Heat of Hydration
Curing
Drying
Concrete Testing
Compressive Strength
Permeability
Durability
Cross Section of Hardened Concrete

Concrete made with siliceous rounded gravel

Concrete made with crushed limestone
Concrete Components

- Cement
- Water
- Fine Aggregate
- Coarse Aggregate
Range in Proportions

Mix 1
- Cement: 15%
- Water: 18%
- Air: 8%
- Fine agg.: 28%
- Coarse agg.: 31%

Mix 2
- Cement: 7%
- Water: 14%
- Air: 4%
- Fine agg.: 24%
- Coarse agg.: 51%

Mix 3
- Cement: 15%
- Water: 21%
- Air: 3%
- Fine agg.: 30%
- Coarse agg.: 31%

Mix 4
- Cement: 7%
- Water: 16%
- Air: 1%
- Fine agg.: 25%
- Coarse agg.: 51%

Air-entrained concrete
Non-air-entrained concrete
Cement Types

- Type I: general purpose portland cement suitable for most uses.
- Type II: moderate sulfate resistant for use in sulfate-rich conditions.
- Type III: high early strength.
- Type IV: hydration retarding.
- Type V: high sulfate resistant.
- Type _A: air entrained variants.
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Admixtures

- Additives introduced during batching to modify the physical properties of a concrete.
- Typically a liquid compound.
- Must come from same manufacturer to assure compatibility.
Admixtures

- Water-Reducing Admixture (WRA)
- Air-Entraining Admixture (AEA)
- Plasticizer
- Accelerant
- Hydration retarders
- Waterproofing
Pozzolans

- Materials that replace portland cement and generate strength.
- Typically a powdered solid:
  - Fly ash
  - Silica fume
  - Lime
W/CM Ratio

- Ratio of mass of water to mass of cementing materials in a concrete mix expressed as a decimal.
- Theoretical minimum w/cm ratio of typical concrete ranges from 0.28 to 0.35.
- Common practice w/cm ratio ranges from 0.40 to 0.55.
W/CM Ratio

- Reducing w/cm ratio is the most effective way to increase the durability of concrete.
- Maintain workability using admixtures while achieving high-strength and low permeability.
Typical Relationships of Strength to W/CM-Ratio

28-day strength
Moist cured cylinders

Compressive strength, MPa

Compressive strength, psi

Water-cement ratio
Advantages of Reducing Water Content

- Increased strength
- Lower permeability
- Increased resistance to weathering
- Better bond between concrete and rebar
- Reduced drying shrinkage and cracking/curling
- Less volume change from wetting and drying
W/CM Ratio

To Calculate (by weight):

- \( w/cm = \frac{\text{water wgt}}{\text{cement wgt}} \)
  
  - = \frac{300 \text{ lbs}}{450 \text{ lbs} + 150 \text{ lbs}}
  
  - = \frac{300}{600}
  
  - = .50
Concrete Components

- The only construction material that when it is delivered has none of its intended properties.
Concrete Components

- Batching
- Mixing
- Delivery
- Placement
- ACI 301 and 302 and ASTM C94
Concrete Components

Batching

- Set forth in ACI 302.1R section 7.1
- Cement, aggregate, water are measured by mass (weight)
- Admixtures and pozzolans must be carefully measured; liquids are preferred.
Concrete Components

Mixing

- Occurs inside drum of truck.
- Sufficient time to develop the required slump and air content.
- Water withheld at batch plant and added onsite.
Concrete Components

Delivery

• Pot life depends on temperature and humidity and mix design.

• Maximum of 90 minutes.

• Maximum of 300 drum revolutions.
Who Owns the Concrete?

They own it

Inspection

You own it
Hydration

- Is the chemical reaction between the cement and water in which new compounds with strength producing properties are formed.

Heat of Hydration

- Is the heat given off during the chemical reaction as the cement hydrates.
Curing

- Maintenance of moisture and temperature in concrete for a suitable period immediately following placement & finishing to develop desired physical properties:
  - ✓ Time
  - ✓ Temperature
  - ✓ Moisture
Drying

- Independent of curing. Drying is the process of free-water (water not consumed in hydration) volatilizing from the concrete.
- Concrete will cure even when placed under water.
- Water that dries out leaves void space in the cement.
Workability

That property of freshly mixed concrete that determines its working characteristics:

- Mixing
- Placing
- Compacted
- Finished
Workability & Consolidation
Workability

Flowable
Placement
Pot-life
Important
constructability
property

Orange safety vest→
Improving Workability

- Batch concrete with low w/cm ratio and use WRA or plasticizer to achieve desired slump.
- If more workability is needed on-site, add additional plasticizer. Water should *not* be added on-site unless mix is adjusted at the batch plant.
Compressive Strength

- Is defined as the measured maximum resistance of a concrete specimen to an axial load at an age of 28-days (ASTM C42-10).
  
  ✓ Most general-construction concrete: 20 to 40 Mpa (3000 to 6000 psi).
  
  ✓ High-strength concrete by definition: 70 MPa or greater (>10000 psi).

[Image of a slide with the text]
Compressive Strength & Loading

- Slabs and pads are supported by compacted, structural fill.
- Slabs and pads are designed to be in compression.
- The spring coefficient (k) of the soil determines the strength of the slab/pad.
- Tensile/shear strength $\sim 10\%$ of $f'$c.
Compressive Strength & Loading

- Graph showing Compressive Strength vs. Time (Days)
- Graph showing Compressive Strength vs. Maturity, TTF (°C-hours)
- Graph showing Maturity Curve Stoneway 8048-H
- Graph showing Strength-Maturity Correlation
Compressive Strength & Loading

- 0 days: 0 psi
- 7 days: 4500 psi, 4640 psi
- 28 days: 6296 psi, 6396 psi

Mathematical equations:

- For 0 days: $y = 1931\ln(x) + 172.8$
- For 7 days: $y = 1897.7\ln(x) + 153.21$
- For 28 days: $y = 1931\ln(x) + 172.8$ (approx. 80% increase)

Graph showing compressive strength over time.
Compressive Strength & Loading

Test Case

- Day 14: 5200 psi
- MOR: $5\sqrt{f'c} = 360$ psi
- MOR: $9\sqrt{f'c} = 650$ psi
- Shear strength for the portion of the load not supported by the soil.
Compressive Strength & Loading

- Greatest strength in the core.
- “Free edges” have less strength.
- A side edge would be ½ the MOR.
- A corner would be ¼ MOR.
Compressive Strength & Loading
Permeability

- Amount of water migration through concrete when the water is under pressure.

- The ability of concrete to resist penetration by water or other substances (liquids, gas, ions, etc.).

- For most concretes low-permeability is desired.
Durability

- The ability of a concrete to achieve the designed service life without excess deterioration.
- Is not only dependent upon concrete strength.
- A typical minimum service life for normal concrete is at least 50 years. 75 years is proposed by ACI and PCA. Nuclear reactors 120 years.
Ability of the concrete to resist its environment:

- Weathering/erosion
- Moisture
- Freezing and thawing
- Temperature changes
- Physical impact
- Chemical attack
Durability

Three keys to durability:

• Low w/cm
• Air entrainment
• Curing
Durability

Resistance to:
- Weathering/erosion
- Physical impact
- Chemical attack
- Physical stresses
- Fatigue
Durability

- The ability of a concrete to achieve the designed *service life* without excess deterioration.

- Is not dependent upon concrete strength.

- A typical minimum service life for normal concrete is at least 50 and often 75 years.
Concrete Testing

Field sampling and testing of fresh concrete:

- Air entrainment
- Slump cone

Laboratory testing of castings:

- 28-day compressive strength ($f'_c$)
Concrete Testing

Air entrainment:
• 5% air content +/-1.0%

Slump:
• 3 to 4 1/2 inches

28-day $f'_c$
• Typically 4,000 psi
Air Entrainment

The only effective protection against freeze/thaw damage.

Consists of:

- Microscopic bubbles (1 μm to 1 mm)
- Evenly dispersed (.008 in. spacing)
- At 4% by volume (±1%)
Air Entrainment

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Air Entrainment

Field Measurement (fresh):
- Volumetric method by ASTM C 173
- Pressure method by ASTM C 231
  - Is most commonly used
  - Must be corrected for aggregate porosity
  - Measures total air (entrained + entrapped air)
Air Entrainment

All concrete contains air bubbles:

- Large, entrapped, *accidental* air
- Small, entrained, *intentional* air
  - Made small by the type of agent
  - Stabilized by static charge
  - Kept spherical by surface tension
Air Entrainment

Large bubbles: low shell to air ratio.

Small bubbles: high shell to air ratio.
Hot-Weather Concrete Practice

Potential problems:
- Early setting
- Slump loss (workability)
- Rapid drying shrinkage
- Plastic shrinkage
- Other?
Hot-Weather Concrete Practice
Hot-Weather Concrete Practice

General weather conditions that may trigger hot-weather practices:

- Temperatures >90°F
- Relative humidity <25%
- Winds in excess of 20 mph
Hot-Weather Concrete Practice

Recommended mitigation for high temperatures:

- Reduce cement content
- Add WRA or retarding admixtures
- Chill mix water (ice!?)
- Cool rebar
- Use water fog
Hot-Weather Concrete Practice

Recommended mitigation for windy conditions:

- Use water fog
- Use wet burlap
- Apply pigmented curing agents
- Cover with plastic sheeting
Cold-Weather Concrete Practice

General weather conditions that may trigger hot-weather practices:

- Temperatures <35°F
- Winds in excess of 10 mph
Cold-Weather Concrete Practice

Recommended mitigation for freezing temperatures:

- Warm mix water
- Accelerant admixture (non Cl-)
- Cover with insulating blankets
- Provide heat
Corroded Steel

Cover (clear cover) is what protects the reinforcement from degradation.

- 1.5 inches for above-grade elements.
- 3 inches for below-grade elements.
- Good quality concrete with appropriate cover should protect reinforcement from corrosion for 50 years.
Corroded Steel Due to Chlorides or Carbonation
Corroded Steel
Freeze-Thaw Attack

- Non-air-entrained
- High w/cm ratio
- Air-entrained
- Low w/cm ratio

samples subjected to 150 Cycles of freeze-thaw
Freeze-Thaw Attack
Freeze-Thaw Attack
Freeze-Thaw Prevention

- Air entrainment is the only effective method of prevention.
- The capture and stabilization of a microscopic air-void system using chemical admixtures (AEA).
- Must be microscopic and well-dispersed: (≈5%, <1mm, .0007 in).
Alkali-Aggregate Reactivity (AAR)

- Is a reaction between the active mineral constituents of reactive aggregates and the sodium and potassium alkali hydroxides and calcium hydroxide in the concrete.

✓ Alkali-Silica Reaction (ASR)
✓ Alkali-Carbonate Reaction (ACR)
Alkali-Silica Reactivity (ASR)
Alkali-Silica Reactivity (ASR)

- Control ASR with:
  - Fly ash
  - Slag
  - Calcined clay
  - Blended cement
  - Low-alkali cement
  - Lithium compounds
Common Problems

- Workmanship defects
- Material defects
- Environmental exposure
Common Problems

Workmanship defects:

- Poor consolidation – concrete is too stiff; not prepared for challenges; lack of vibration.
- Overworking – depleting the air-entrainment.
- Re-tempering the surface.
Common Problems

Material defects
- High w/cm ratio
- Lack of air-entrainment
- Reactive aggregate
- Non-durable particles
- Admixture incompatibility