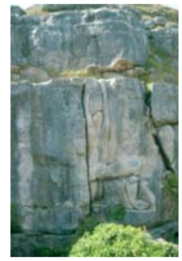
Properties of Concrete

- ***Concrete*** is an artificial conglomerate stone made essentially of Portland cement, water, and aggregates.

Properties of Concrete

- While cement in one form or another has been around for centuries, the type we use was invented in 1824 in Britain.
- It was named Portland cement because it looked like the stone quarried on the Isle of Portland.



Properties of Concrete

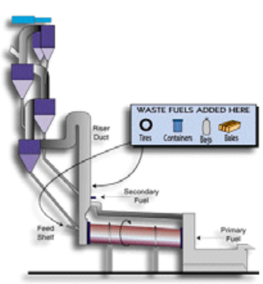
- Joseph Aspdin (1779-1835) patented the clay and limestone cement known as Portland cement in 1824.
- Joseph's son, William Aspdin's kiln used to make the first genuine Portland cement.
- Portland cement was first used in the civil engineering project by Isambard Kingdom Brunel (1806-1859), as the lining of the Thames Tunnel.

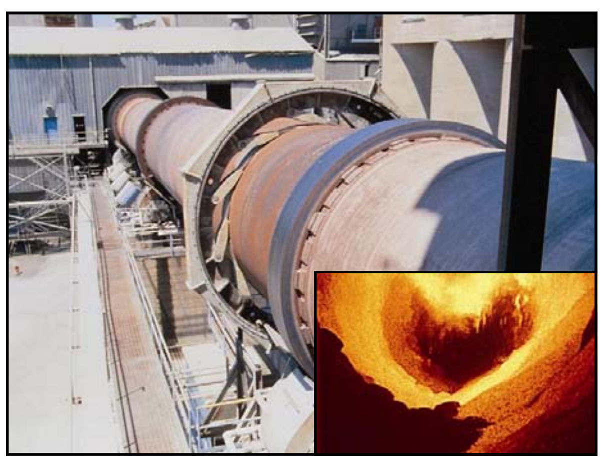
Properties of Concrete

- Portland cement is produced by mixing ground limestone, clay or shale, sand and iron ore.
- This mixture is heated in a rotary kiln to temperatures as high as 1,600 degrees Celsius.
- The heating process causes the materials to break down and recombine into new compounds that can react with water in a crystallization process called hydration.

Portland Cement

- The raw ingredients of Portland cement are iron ore, lime, alumina and silica.
- These are ground up and fired in a kiln to produce a clinker.
- After cooling, the clinker is very finery ground.





Properties of Concrete

- When first mixed the water and cement constitute a paste which surrounds all the individual pieces of aggregate to make a plastic mixture.
- A chemical reaction called ***hydration*** takes place between the water and cement, and concrete normally changes from a plastic to a solid state in about 2 hours.
- Concrete continues to gain strength as it cures.
- ***Heat of hydration*** **-** is the heat given off during the chemical reaction as the cement hydrates.

Properties of Concrete

- Tricalcium silicate – C_3S

- Dicalcium silicate – C_2S

Properties of Concrete

- Tricalcium aluminate – C_3A

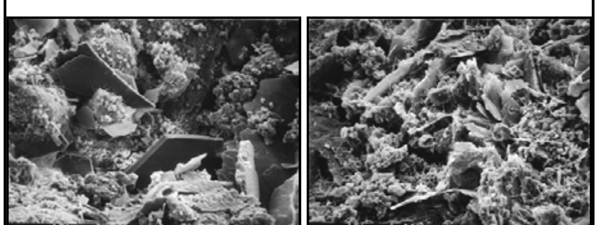
- Tetracalcium aluminoferrite

Properties of Concrete

- Tricalcium aluminate – C_3A

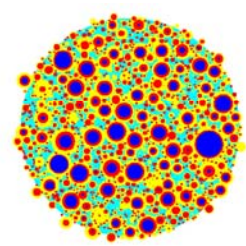
Properties of Concrete

- Scanning-electron micrographs of hardened cement paste



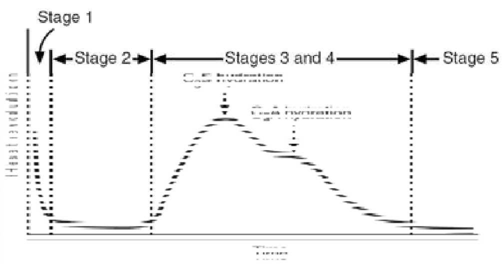
Properties of Concrete

- Image shown is a two-dimensional slice from a three-dimensional spherical computational volume
- Unhydrated cement cores are dark blue,
- Inner C-S-H product is red,
- Outer C-S-H project is yellow, and
- Water-filled space is light blue



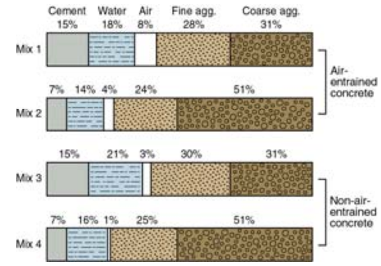
Properties of Concrete

- Stages of hydration:



Properties of Concrete

- Range in proportions of materials used in concrete, by absolute volume.



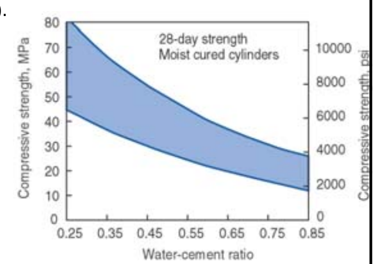
- Bars 1 and 3 represent rich mixes with small size aggregates.
- Bars 2 and 4 represent lean mixes with large size aggregates.

Water/Cement Ratio

- The single most important indicator of strength is the ratio of the water used compared to the amount of cement (*w/c* ratio)
- Basically, the lower this ratio is, the higher the final concrete strength will be.
- This concept was developed by Duff Abrams of The Portland Cement Association in the early 1920s and is in worldwide use today.

Water/Cement Ratio

- A minimum *w/c ratio* (water-to-cement ratio) of about 0.3 by weight is necessary to ensure that the water comes into contact with all cement particles (thus assuring complete hydration).
- Typical values are in the 0.4 to 0.6

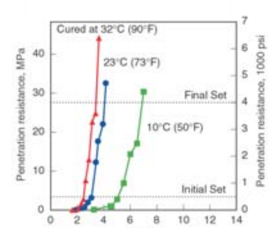


Water/Cement Ratio

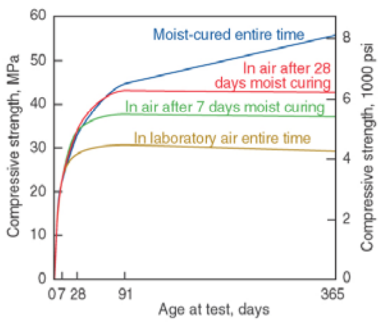
- Advantages of low water/cement ratio:
  - Increased strength
  - Lower permeability
  - Increased resistance to weathering
  - Better bond between concrete and reinforcement
  - Reduced drying shrinkage and cracking
  - Less volume change from wetting and drying

Concrete Curing

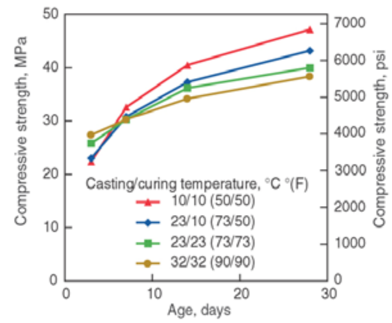
- ***Curing*** - maintenance of a satisfactory moisture content and temperature in concrete for a suitable period of time immediately following placing & finishing so that the desired properties may develop.
- Factors that effect curing:
  - Time
  - Temperature
  - Moisture



Concrete Curing

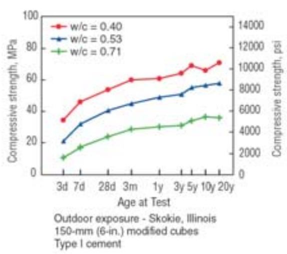


Concrete Curing



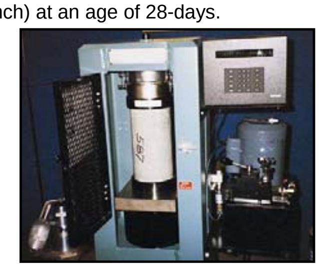
Concrete Curing

- Concrete strength gain versus time for concrete exposed to outdoor conditions. Concrete continues to gain strength for many years when moisture is provided by rainfall and other environmental sources.



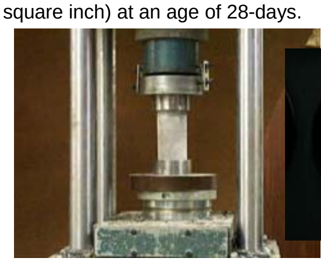
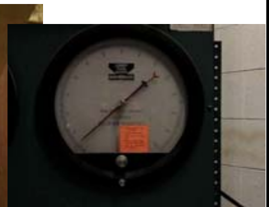
Compressive Strength

- ***Compressive Strength*** - is defined as the measured maximum resistance of a concrete or mortar specimen to an axial load, usually expressed in *psi* (pounds per square inch) at an age of 28-days.

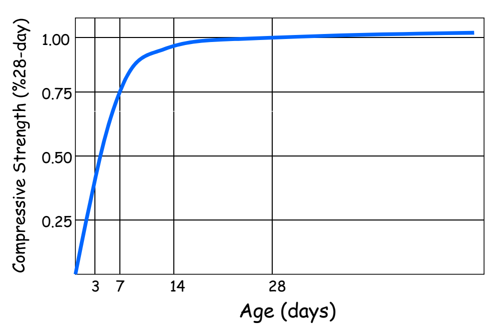


Compressive Strength

- ***Compressive Strength*** - is defined as the measured maximum resistance of a concrete or mortar specimen to an axial load, usually expressed in *psi* (pounds per square inch) at an age of 28-days.

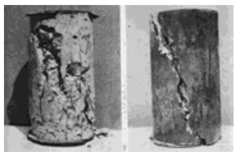



Properties of Concrete

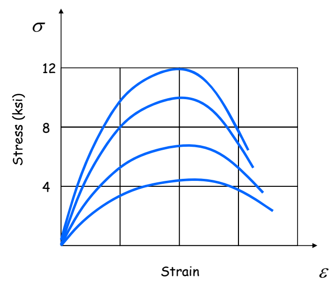


Properties of Concrete

- During the first week to 10 days of curing it is important that the concrete not be permitted to freeze or dry out
- In practical terms, about 90% of its strength is gained in the first 28 days.
- Concrete compressive strength depends upon many factors:
  - quality and proportions of the ingredients
  - the curing environment.



Stress–Strain Diagram



Concrete Material Properties

- Most structural concrete have f'_c values in the 3,000 to 5,000 psi range.
- High-rise buildings sometimes utilize concrete of 12,000 or 15,000 psi
- Concrete has no linear portion to its stress-strain curve, therefore it is difficult to measure the modulus of elasticity

Concrete Material Properties

- For concretes up to about 6,000 psi it can be approximated as:

$$E = 33w^{1.5}\sqrt{f'_c}$$

- where w is the unit weight (pcf), f'_c is the cylinder strength (psi).

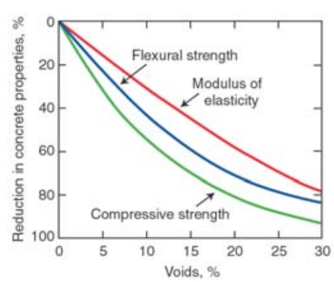
Concrete Material Properties

- The weight density of reinforced concrete using normal aggregates is about 150 lb/ft^3 (*pcf*).
- If 5 *pcf* of this is allowed for the steel and w is taken as 145 *pcf* then:

$$E = 57{,}000\sqrt{f'_c}$$

Concrete Material Properties

- Effect of voids in concrete on modulus of elasticity, compressive strength, and flexural strength



Freeze-Thaw Resistance

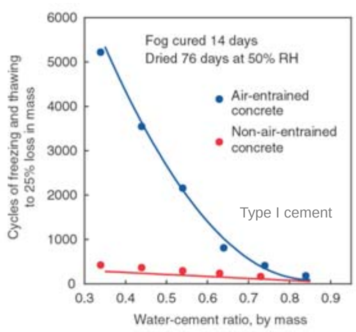
- Concrete used in structures and pavements is expected to have long life and low maintenance.
- It must have good durability to resist anticipated exposure conditions.
- The most potentially destructive weathering factor is freezing and thawing while the concrete is wet, particularly in the presence of deicing chemicals.
- Deterioration is caused by the freezing of water and subsequent expansion in the paste, the aggregate particles, or both.

Specimens Subjected to 150 Cycles of Freezing and Thawing

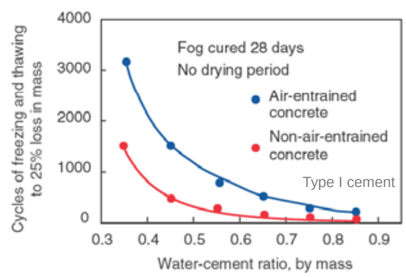
- Non-air-entrained
- High water-cement ratio

- Air-entrained
- Low water-cement ratio

Freeze-Thaw Resistance



Freeze-Thaw Resistance



Concrete Shrinkage

- As concrete cures it shrinks because the water not used for hydration gradually evaporates from the hardened mix
- Concrete, like all materials, also undergoes volume changes due to thermal effects.
- The heat from the exothermic hydration process adds to this problem.

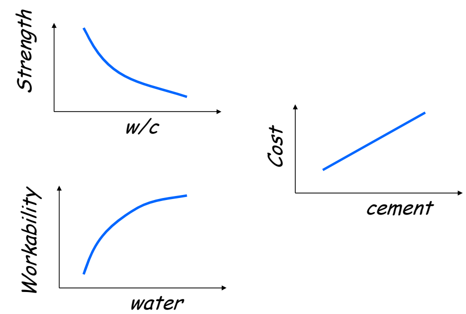
Concrete Shrinkage

- Since concrete is weak in tension, it will often develop cracks due to such shrinkage and temperature changes.
- *Consider a freshly placed concrete slab-on-grade*

Mix Proportions

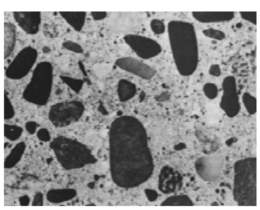
- The ingredients of concrete can be proportioned by weight or volume.
- The goal is to provide the desired strength and workability at minimum expense.
- A low *w/c* ratio is used to achieve strong concrete.
- *Could you increased the cement content and use enough water for good workability and still have a low* w/c *ratio?*

Concrete Mix Design Relationships



Aggregate Size and Shape

- Larger aggregate sizes have relatively smaller surface areas (for the cement paste to coat)
- Use the largest practical aggregate size and the stiffest practical mix.

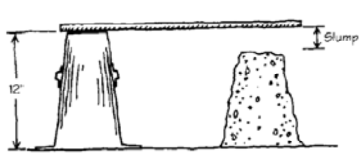


Workability

- ***Workability*** - that property of freshly mixed concrete that determines its working characteristics, i.e. the ease with which it can be mixed, placed, compacted and finished.
- Factors effecting workability:
  - Method and duration of transportation
  - Quantity and characteristics of cementing materials
  - Concrete consistency (slump)
  - Aggregate grading, shape & surface texture
  - % entrained air
  - Water content
  - Concrete & ambient air temperature
  - Admixtures

Slump Test

- A good indication of the water content of a mix and thus the workability) can be had from a standard slump test.



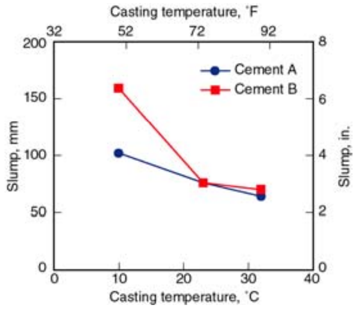
- Most concrete mixes have slumps in the 2- to 5-in range.

Slump Test

- A good indication of the water content of a mix and thus the workability) can be had from a standard slump test.

Slump Test

Slump Test



Consolidation

- Good consolidation (left) is needed to achieve a dense and durable concrete.
- Poor consolidation (right can result in early corrosion of reinforcing steel and low compressive strength.

Curing of Concrete

Why cure concrete? Curing serves two main purposes:

- it retains moisture in the slab so that the concrete continues to gain strength
- it delays drying shrinkage until the concrete is strong enough to resist shrinkage cracking

Types of Portland Cement

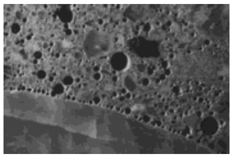
- There are five basic types of Portland cement in use today:
  - **Type I** General purpose
  - **Type II** Sulfate resisting, concrete in contact with high sulfate soils
  - **Type III** High early strength, which gains strength faster than Type I, Enabling forms to be removed sooner
  - **Type IV** Low heat of hydration, for use in massive construction
  - **Type V** Severe sulfate resisting

Aggregates

- **Coarse aggregates** are larger than 3/8 inch in diameter
- **Fine aggregate** (sand) is made up of particles which are smaller than 3/8 " in diameter
- The quality of aggregates is very important since they make up about 60 to 75% of the volume of the concrete
- Normal and lightweight concrete

Admixtures

- Admixtures are chemicals which are added to the mix to achieve special purposes
- There are basically four types:
  - air-entraining agents,
  - workability agents,
  - retarding agents, and
  - accelerating agents

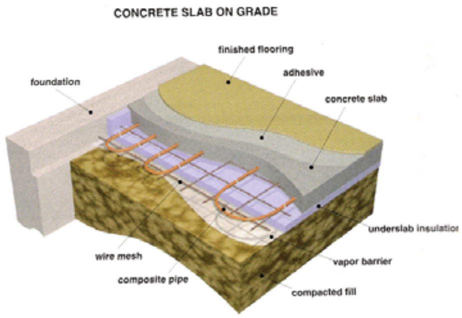


- Also test batches of concrete is investigate the effects of concrete performance

The ACI Code

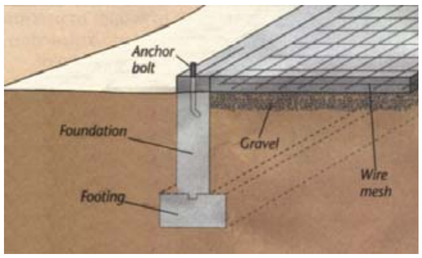
- The American Concrete Institute (ACI), based in Detroit, Michigan, is an organization of design professionals, researchers, producers, and constructors.
- One of its functions is to promote the safe and efficient design and construction of concrete structures.
- An important ACI publication is the *Building Code Requirements for Reinforced Concrete and Commentary*.

Concrete Slabs



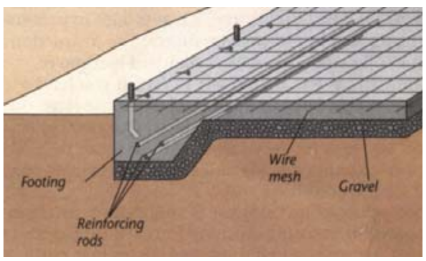
Concrete Slabs

- T-shaped foundations are used in areas where the ground freezes.
- First, the footing is placed
- Second, the walls are constructed and poured
- Lastly, the slab is placed.



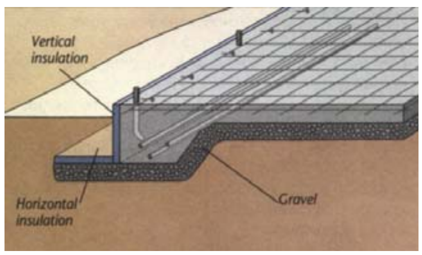
Concrete Slabs

- Slab on grade used in areas where ground does not freeze.
- The edges of the slab-on-grade are thicker than the interior of the slab.
- The slab-on-grade is monolithic (poured all at one time).



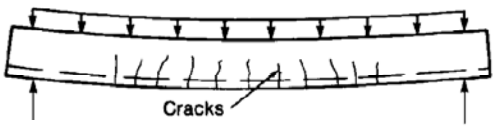
Concrete Slabs

- Only works with a heated structure.
- Has the benefits of a the slab-on-grade method (concrete poured monolithically) in areas subject to frost.
- Concrete is poured in one operation versus 3 pours required for T-shaped foundations.



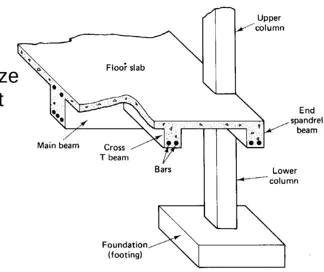
Why Consider Creep?

- Creep is increasing deformation that takes place when a material sustains a high stress level over a long time period.
- In a beam, the additional long term deflection due to creep can be as much as two times the initial elastic deflection



Why Use Reinforcing in Concrete?

- The purpose of this reinforcing is to accommodate tensile stresses and to minimize the width of cracks that do develop.
- To control creep use compression steel.



Properties of Concrete

The End