Seventh Lecture

Concrete

A composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate

. Because the tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars, in which case it is known as reinforced concrete.

Cement

Cement is the “glue” that binds the concrete ingredients together and is instrumental for the strength of the composite.

The primary product of cement hydration is a complex and poorly crystalline calcium-silicate hydroxide gel (or CSH). A secondary product of hydration is calcium hydroxide, a highly crystalline material. A category of siliceous materials known as pozzolans have little or no cementitious value, but in finely divided form and in the presence of moisture will react chemically with calcium hydroxide to form additional CSH. This secondary hydration process has a generally beneficial effect on the final concrete properties. Examples of pozzolans are fly ash, ground granulated blast-furnace slag, and micro silica or silica fume. The American Society for Testing and Materials (ASTM) defines five types of cement, specifying for each the mineral composition and chemical and physical characteristics such as fineness. The most common cement is Type I. Type III cement is used if more rapid strength envelopment is required. The other types are characterized by either lower heat of hydration or better sulfate resistance than that of Type I cement.

Aggregate

The aggregate is a granular material, such as sand, gravel, crushed stone, or iron-blast furnace slag. It is graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone.

the smaller particles fill the void spaces between the larger particles. Such dense packing minimizes the amount of cement paste needed and generally leads to improved mechanical and durability properties of the concrete.
The aggregate constitutes typically 75% of the concrete volume, or more, and therefore its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles.

*A**dmixture**s*

mineral and chemical admixtures that may be added to the concrete. The four most common admixtures will be discussed.

1. Air-entraining agents

are chemicals that are added to concrete to improve its freeze–thaw resistance. Concrete typically contains a large number of pores of different sizes, which may be partially filled with water. If the concrete is subjected to freezing temperatures, this water expands when forming ice crystals and can easily fracture the cement matrix, causing damage that increases with each freeze–thaw cycle. If the air voids created by the air-entraining agent are of the right size and average spacing, they give the freezing water enough space to expand, thereby avoiding the damaging internal stresses

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2. **Water-reducing admixtures**

superplasticizers, are chemicals that lower the viscosity of concrete in its liquid state, typically by creating electrostatic surface charges on the cement and very fine aggregate particles. This causes the particles to repel each other, thereby increasing the mix flow ability, which allows the use of less water in the mix design and results in increased strength and durability of the concrete

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3**. Retarding**

delay the setting time, which may be necessary in situations where delays in the placement of concrete can be expected. Accelerators shorten the period needed to initiate cement hydration—for example, in emergency repair situations that call for the very rapid development of strength or rigidity

4. Color pigments in powder or liquid form may be added to the concrete mix to produce colored concrete. These are usually used with white Portland cement to attain their full coloring potential.

Reinforcing steels. Because of concrete's relatively low tensile strength, it is typically reinforced with steel bars Reinforcing steel usually has a nominal yield strength of 60,000 lb/in.2 (414 MPa).

protection The alkalinity of the cement paste generally provides sufficient of the steel against corrosion. However, corrosion protection is often breached, for example, in highway bridge decks with continuous pore structure or traffic-induced cracks that permit the deicing chemicals used in winter to penetrate the protective concrete cover. Additional protective measures may be necessary, such as using epoxy coatings on the bars, noncorrosive steels, or nonmetallic reinforcement.

Cement paste plus fine aggregate is called mortar or concrete matrix. Mortar plus coarse aggregate constitutes concrete. Concrete reinforced

MIX DESIGN

Any excess water creates pores which, together with any air-filled pores, do not contribute to the material strength. The result is a drastic decrease in strength as a function of increasing the w/c ratio. On the other hand, too low w/c ratios cause poor workability of the concrete. For practical reasons, the w/c ratio typically varies between 0.4 and 0.6. The other important mix design variables are the cement-to-aggregate ratio and the fine-to-coarse aggregate ratio. Also, the maximum aggregate size is of importance. And since cement is the most expensive bulk ingredient, the mix design will generally aim at the least amount of cement necessary to achieve the design objectives.

Construction practice

Precast concrete refers to any structure or component that is produced at one site, typically in a precasting plant, and then transported in its hardened state to its final destination.

. if dropped too far, the heavy or big aggregate particles can settle and lighter mix components, such as water, tend to rise.

During placement, large amounts of air are entrapped in the mix, which lowers the strength of the hardened concrete. Much of the air is removed by compaction, which is achieved by either immersing high-frequency vibrators into the fresh concrete or attaching them to the outside faces of the formwork. Care must be taken to avoid excessive vibration; otherwise the heavy aggregate particles settle down and the light mixing water rises to the surface.
For underwater construction, the concrete is placed in a large metal tube, called a tremie, with a hopper at the top and a valve arrangement at the submerged end. For so-called shotcrete applications such as tunnel linings

and swimming pools, the concrete mixture is blown under high pressure through a nozzle directly into place to form the desired surface

Curing

For example, in hot or dry weather large exposed surfaces will lose water by evaporation. This can be avoided by covering such surfaces with sheets of plastic or canvas or by periodically spraying them with water. In precast concrete plants, concrete elements are often steam-cured, because the simultaneous application of hot steam and pressure accelerates the hydration process, which permits high turnover rates for the formwork installations.

Properties of fresh concrete.

The most important property of fresh concrete is its workability or flow ability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete. The mold is then lifted vertically, and the resulting loss in height of the concrete cone, or the slump value, is indicative of the concrete's workability.

Properties of hardened concrete.

Most commercially produced concrete has compressive strengths between 3000 and 6000 lb/in.2 (20 and 40 MPa).

During hydration and especially if allowed to dry after hardening, the concrete volume decreases by a small amount because of shrinkage. If this shrinkage is restrained somehow, it can lead to cracking.

A concrete member or structure subjected to external load will undergo deformations which, up to a point, are proportional to the amount of applied load. If these loads remain in place for an appreciable time (months or years), these deformations will increase due to a material property called creep.

Durability. Durability is the ability of a material (or structure) to maintain its various properties throughout its design or service life.

There can be numerous causes for loss of durability or deterioration of concrete structures. The most common one is an excessive amount of cracking or pore structure.

Larger cracks provide easy access for such agents to the steel, thereby promoting corrosion.

The concrete itself may deteriorate or weather, especially if subjected to many cycles of freezing and thawing, during which the pressure created by the freezing water progressively increases the extent of internal cracking. In addition, carbon in the atmosphere can react chemically with the cement hydration products. This process is known as carbonation.
It lowers the pH of the concrete matrix to the point where it can no longer protect the steel against corrosion.

Most types of aggregate used for concrete production are inert; that is, they do not react chemically with the cement or hydration products. However, there are various aggregate types, including those containing amorphous silica such as common glass, which react chemically with the alkali in the cement.
In the presence of moisture, the alkali–aggregate reaction products can swell and cause considerable damage.

Under repeated load applications, structures can experience fatigue failure, as each successive load cycle increases the degree of cracking and material deterioration to the point where the material itself may gradually lose its strength or the increased extent of cracking is the source of loss of durability.
Thermal and other properties. The heavy weight of concrete [its specific gravity is typically 2.4 g/cm3 (145 lb/ft3)] is the source of large thermal mass. concrete structures can moderate extreme temperature cycles and increase the comfort of occupants.

Special concretes and recent developments.

Lightweight concrete

because of the large stresses caused by their own heavy weight, floor slabs are often made lighter by using special lightweight aggregate. To further reduce weight, special chemical admixtures are added, which produce large porosity.
Such high porosity (in either the matrix or the aggregate particles themselves) improves the thermal resistance of the concrete as well as sound insulation, especially for higher frequencies. However, because weight density correlates strongly with strength, ultra lightweight concretes [1.1 g/cm3 (70 lb/ft3) and less] are used only for thermal or sound insulation purposes and are unsuitable for structural applications.

. ***Heavyweight concrete***. When particularly high weight densities are needed, such as for shielding in nuclear reactor facilities

Fiber-reinforced concrete

Fibers may be metallic (primarily steel), synthetic (such as polypropylene, nylon, polyethylene, polyvinyl alcohol, and alkali-resistant glass), or natural (such as sisal, coconut, and rice husk).

fibers give the concrete matrix tensile strength, ductility, and energy absorption capacities that it otherwise would not have.

fiber-reinforced concrete

Whereas in fiber-reinforced concrete the fibers are short [usually no longer than 2 in. (5 cm)]

Ultra-high-strength concrete. Whereas concretes with compressive strengths of 6000 to 12,000 lb/in.2 (40 to 85 MPa) can now be categorized as high-strength

Other characteristics of this material are low water–cement ratios, carefully selected high-strength aggregates, and small steel fibers

. ***"Green" concrete***

the production of 1 ton of portland cement causes the release of 1 ton of carbon dioxide (CO_2) into the atmosphere The most significant step is the replacement of portland cement by other cementitious or pozzolanic materials, preferably materials that are byproducts of industrial processes, such as fly ash (the by-product of coal-burning power plants) and granulated blast furnace slag (a by-product of the steel industry)