DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING & TECHNOLOGY

Topics to be covered:

- Introduction to Concrete and History of Concreting
- Properties of Concrete
- Factors affecting Properties of Concrete
- Properties of Reinforcements
- Problems related to the Topics Discussed

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INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- Concrete is the most widely used material in the world. It plays an important role in infrastructure and private buildings construction.
- Understanding the basic behaviors of concrete is essential for civil engineering students to become civil engineering professionals.
- Concrete is a manmade building material that looks like stone.
- The word “concrete” is derived from the Latin *concretus, meaning “to grow together.” Concrete is a composite material composed* of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together.
- Alternatively, we can say that concrete is a composite material that consists essentially of a binding medium in which are embedded particles or fragments of aggregates.
- The simplest definition of concrete can be written as: **CONCRETE = FILLER + BINDER.**
- Depending on what kind of binder is used, concrete can be named in different ways.
- For instance, if a concrete in made with non-hydraulic cement, it is called non-hydraulic cement concrete; if a concrete made of hydraulic cement, it is called hydraulic cement concrete; if a concrete is made of asphalt, it is called asphalt concrete; if a concrete is made of polymer, it is called polymer concrete.
- Non-hydraulic cement concretes are the oldest used in human history. As early as around 6500 BC, non-hydraulic cement concretes were used by the Syrians and spread through Egypt, the Middle East, Crete, Cyprus, and ancient Greece.
- The non-hydraulic cements used at that time were gypsum and lime.
- Lime was obtained by calcining limestone with a reaction of

$$CaCO_3 \xrightarrow{1000^\circ C} CaO + CO_2$$

When CaO is mixed with water, it can react with water to form $CaO + H_2O \xrightarrow{\text{Ambient Temperature}} Ca(OH)_2$

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- When mixed with water, half-water gypsum could turn into two-water gypsum and gain strength:

$$2CaSO4 \cdot 12\ H_2O + 3H_2O^{\text{ambient temperature}} \text{-------------}\rightarrow 2CaSO4 \cdot 2H_2O$$

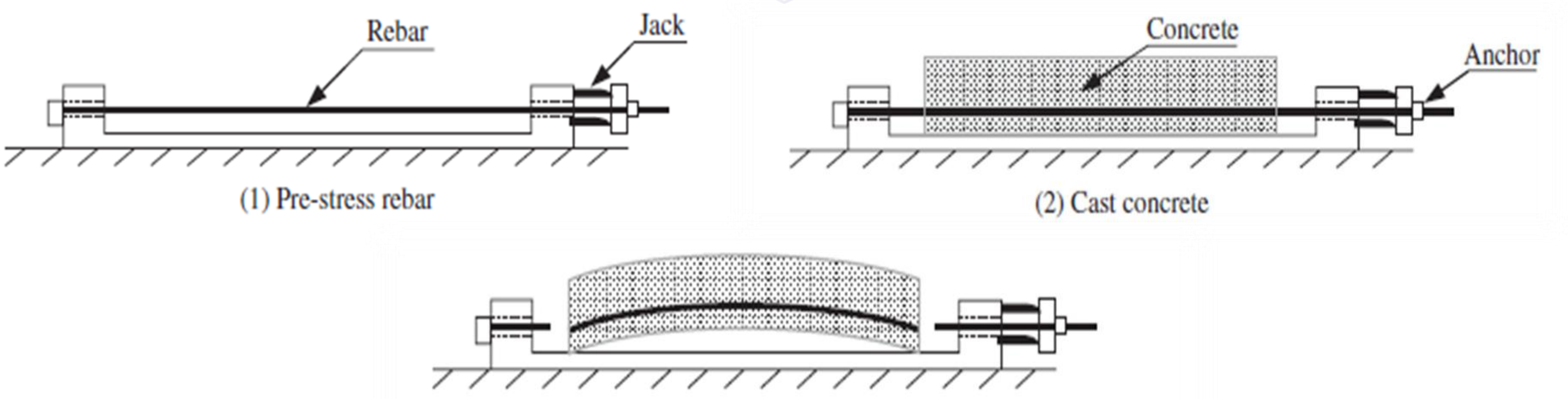
- The Egyptians used gypsum instead of lime because it could be calcined at much lower temperatures. As early as about 3000 BC, the Egyptians used gypsum mortar in the construction of the Pyramid of Cheops.
- A hydraulic lime was developed by the Greeks and Romans using limestone containing argillaceous (clayey) impurities.
- Thus, hydraulic lime mortars were used extensively for hydraulic structures from second half of the first century BC to the second century ad However, the quality of cementing materials declined throughout the Middle Ages.
- High-quality mortars disappeared for a long period. In 1756, John Smeaton was commissioned to rebuild the Eddy stone Light house off the coast of Cornwall, England.
- Realizing the function of siliceous impurities in resisting water, Smeaton conducted extensive experiments with different limes and Pozzolana, and found that limestone with a high proportion of clayey materials produced the best hydraulic lime for mortar to be used in water.
- After Smeaton's work, development of hydraulic cement proceeded quickly James Parker of England filed a patent in 1796 for a natural hydraulic cement made by calcining nodules of impure limestone containing clay.

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- Vicat of France produced artificial hydraulic lime by calcining synthetic mixtures of limestone and clay.
- Portland cement was invented by Joseph Aspdin of England.
- The name Portland was coined by Aspdin because the color of the cement after hydration was similar to that of limestone quarried in Portland, a town in southern England.
- Portland cement was prepared by calcining finely ground limestone, mixing it with finely divided clay, and calcining the mixture again in a kiln until the CO_2 was driven off. This mixture was then finely ground and used as cement.
- It was Isaac Johnson who first burned the raw materials to the clinkering temperature in 1845 to produce modern Portland cement.
- After that, the application of Portland cement spread quickly throughout Europe and North America.
- The main application of Portland cement is to make concrete.
- It was in Germany that the first systematic testing of concrete took place in 1836. The test measured the tensile and compressive strength of concrete.
- Aggregates are another main ingredient of concrete, and which include sand, crushed stone, clay, gravel, slag, and shale.
- Plain concrete made of Portland cement and aggregate is usually called the first generation of concrete.
- The second generation of concrete refers to steel bar-reinforced concrete.
- Coignet had an exhibit at the 1855 Paris Exposition to show his technique of reinforced concrete. At the exhibit, he forecast that the technique would replace stone as a means of construction.
- In 1856 he patented a technique of reinforced concrete using iron tyrants. In 1861 he put out a publication on his techniques.
- Reinforced concrete was further developed by Hennebique at the end of the 19th century.
- It was realized that performance could be improved if the bars could be placed in tension, thus keeping the concrete in compression.

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- The first reinforced concrete bridge was built in 1889 in the Golden Gate Park in San Francisco, California.
- To overcome the cracking problem in reinforced concrete, pre-stressed concrete was developed and was first patented by a San Francisco engineer as early as 1886.
- Prestressed means that the stress is generated in a structural member before it carries the service load.
- Prestressed concrete was referred to as the third generation of concrete.
- Pre-stressing is usually generated by the stretched reinforcing steel in a structural member.
- According to the sequence of concrete casting, pre-stressing can be classified as pre-tensioning or post-tensioning.
- Pre-tensioning pulls the reinforcing steel before casting the concrete and pre-stress is added through the bond built up between the stretched reinforcing steel and the hardened concrete.
- In the post-tensioning technique, the reinforcing steel or tendon is stretched after concrete casting and the gaining of sufficient strength.
- Prestressed concrete became an accepted building material in Europe after World War II, partly due to the shortage of steel.



(1) Pre-stress rebar
(2) Cast concrete
(3) Release rebar

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- Nowadays, with the development of pre-stressed concrete, long-span bridges, tall buildings, and ocean structures have been constructed.
- As a structural material, the compressive strength at an age of 28 days is the main design index for concrete.
- There are several reasons for choosing compressive strength as the representative index. First, concrete is used in a structure mainly to resist the compression force.
- Second, the measurement of compressive strength is relatively easier.
- Finally, it is thought that other properties of concrete can be related to its compressive strength through the microstructure.
- As early as 1918, Duff Adams found that the compressive strength of a concrete was inversely proportional to the water-to-cement ratio. Hence, a high compressive strength could be achieved by reducing the w/c ratio.
- However, to keep a concrete workable, there is a minimum requirement on the amount of water; hence, the w/c ratio reduction is limited, unless other measures are provided to improve concrete's workability.
- Since the 1960s, the development of high-strength concrete has made significant progress due to two main factors: the invention of water-reducing admixtures and the incorporation of mineral admixtures, such as silica fume, fly ash, and slag.
- Water-reducing admixture is a chemical admixture that can help concrete keep good workability under a very low w/c ratio; the latter are finer mineral particles that can react with a hydration product in concrete, calcium hydroxide, to make concrete microstructure denser.
- In 1972, the first 52-MPa concrete was produced in Chicago for the 52-story Mid-Continental Plaza. In 1972, a 62-MPa concrete was produced, also in Chicago, for Water Tower Place, a 74-story concrete building, the tallest in the world at that time.
- In the 1980s, the industry was able to produce a 95-Mpa concrete to supply to the 225 West Whacker Drive building project in Chicago. The highest compressive strength of 130 MPa was realized in a 220-m-high, 58-story building, the Union Plaza constructed in Seattle, Washington (Caldarone, 2009).

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- Concrete produced after the 1980s usually contains a sufficient amount of fly ash, slag, or silica fume as well as many different chemical admixtures, so its hydration mechanism, hydration products, and other microstructure characteristics are very different from the concrete produced without these admixtures.
- Moreover, the mechanical properties are also different from the conventional concrete; hence, such concretes are referred to as contemporary concretes.
- There have been two innovative developments in contemporary concrete: self-compacting concrete (SCC) and ultra-high-performance concrete (UHPC).
- It is defined as a concrete that can meet special performance and uniformity requirements, which cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices.
- Self-compacting concrete is a typical example of high-performance concrete that can fill in formwork in a compacted manner without the need of mechanical vibration. SCC was initially developed by Professor Okamura and his students in Japan in the late 1980s.

Water Tower Place in Chicago, Illinois, USA

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- In the 1990s, a new "concrete" with a compressive concrete strength higher than 200 Mpa was developed in France. Due to the large amount of silica fume incorporated in such a material, it was initially called reactive powder concrete and later on changed to ultra-high-strength (performance) concrete (UHSC).
- The ultra-high-strength concrete has reached a compressive strength of 800 Mpa with heating treatment. However, it is very brittle, hence, incorporating fibers into UHSC is necessary.

CONCRETE AS A STRUCTURAL MATERIAL :

The term concrete usually refers to Portland cement concrete, if not otherwise specified. For this kind of concrete, the compositions can be listed as follows:

Portland Cement + Water & Admix → Cement Paste + Fine Aggregate → Mortar + Coarse Aggregate → Concrete

- Here it is indicated that admixtures are almost always used in modern practice and thus have become an essential component of contemporary concrete.
- Admixtures are defined as materials other than aggregate (fine and coarse), water, and cement that are added into a concrete batch immediately before or during mixing.
- Concrete is the most widely used construction material in the world, and its popularity can be attributed to two aspects. First, concrete is used for many different structures, such as dams, pavements, building frames, or bridges, much more than any other construction material.
- Second, the amount of concrete used is much more than any other material. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume.
- In a concrete structure, there are two commonly used structural materials: concrete and steel. A structural material is a material that carries not only its self-weight, but also the load passing from other members.
- The designer of a steel structure need only specify the steel complying with a relevant standard, and the constructor needs only to ensure that the correct steel is used and that connections between the individual steel members are properly executed.

INTRODUCTION TO CONCRETE and HISTORY OF CONCRETING :

- It is possible to obtain concrete of specified quality from a ready-mix supplier, but, even in this case, it is only the raw materials that are bought for a construction job.
- Transporting, placing, and, above all, compacting greatly influence the quality of cast concrete structure.
- Moreover, unlike the case of steel, the choice of concrete mixes is virtually infinite and therefore the selection has to be made with a sound knowledge of the properties and behavior of concrete.
- It is thus the competence of the designer and specified that determines the potential qualities of concrete, and the competence of the supplier and the contractor that controls the actual quality of concrete in the finished structure.
- In a concrete structure, concretes mainly carry the compressive force and shear force, while the steel carries the tension force. Moreover, concrete usually provides stiffness for structures to keep them stable.
- Dams are other popular application fields for concrete. The first major concrete dams, the Hoover Dam and the Grand Coulee Dam, were built in the 1930s and they are still standing. The largest dam ever built is the Three Gorges Dam in Hubei province, China.
- In addition, concrete has been widely applied in the construction of airport runways, tunnels, highways, pipelines, and oil platforms. As of now, the annual world consumption of concrete has reached a value such that if concrete were edible, every person on earth would have 2000 kg per year to “eat.” You may wonder why concrete has become so popular.

PROPERTIES OF CONCRETE :

ECONOMICAL: Concrete is the most inexpensive and the most readily available material in the world. The cost of production of concrete is low compared with other engineered construction materials. The three major components in concrete are water, aggregate, and cement. Compared with steels, plastics, and polymers, these components are the most inexpensive, and are available in every corner of the world. This enables concrete to be produced worldwide at very low cost for local markets, thus avoiding the transport expenses necessary for most other materials.

AMBIENT TEMPERATURE-HARDENED MATERIAL : Because cement is a low-temperature bonded inorganic material and its reaction occurs at room temperature, concrete can gain its strength at ambient temperature. No high temperature is needed.

ABILITY TO BE CAST : Fresh concrete is flowable like a liquid and hence can be poured into various formworks to form different desired shapes and sizes right on a construction site. Hence, concrete can be cast into many different configurations.

ENERGY EFFICIENT: Compared with steel, the energy consumption of concrete production is low. The energy required to produce plain concrete is only 450–750 kWh/ton and that of reinforced concrete is 800–3200 kWh/ton, while structural steel requires 8000 kWh/ton or more to make.

EXCELLENT RESISTANCE TO WATER: Unlike wood (timber) and steel, concrete can be hardened in water and can withstand the action of water without serious deterioration, which makes concrete an ideal material for building structures to control, store, and transport water, such as pipelines , dams, and submarine structures.

HIGH-TEMPERATURE RESISTANCE: Concrete conducts heat slowly and is able to store considerable quantities of heat from the environment. Moreover, the main hydrate that provides binding to aggregates in concrete, calcium silicate hydrate (C–S–H), will not be completely dehydrated until 910oC. Thus, concrete can withstand high temperatures much better than wood and steel.

CONTINUED……PROPERTIES OF CONCRETE :

Even in a fire, a concrete structure can withstand heat for 2–6 hours, leaving sufficient time for people to be rescued. This is why concrete is frequently used to build up protective layers for a steel structure.

ABILITY TO CONSUME WASTE: With the development of industry, more and more by-products or waste has been generated, causing a serious environmental pollution problem. To solve the problem, people have to find a way to consume such wastes. It has been found that many industrial wastes can be recycled as a substitute for cement or aggregate, such as fly ash, slag (GGBFS = ground granulated blast-furnaces slag), waste glass, and ground vehicle tires in concrete.

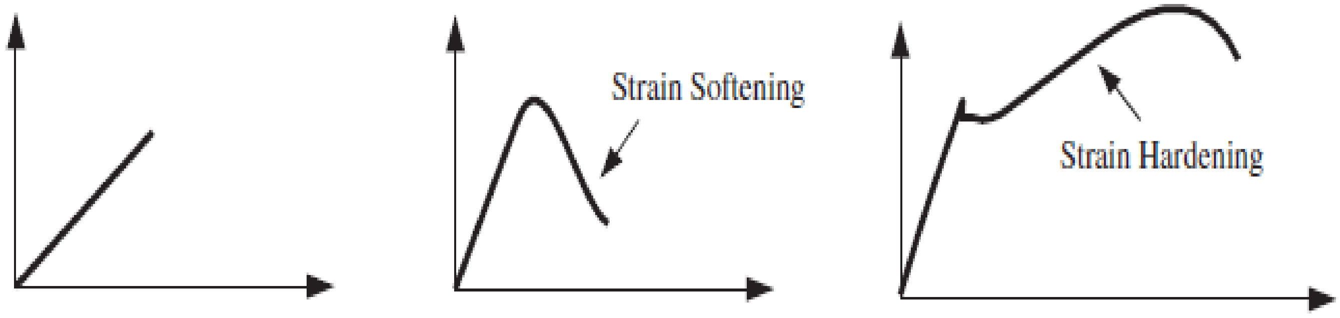
ABILITY TO WORK WITH REINFORCING STEEL : Concrete has a similar value to steel for the coefficient of thermal expansion (steel 1.2×10^{-5}; concrete $1.0–1.5 \times 10^{-5}$). Concrete produces a good protection to steel due to existence of CH and other alkalis (this is for normal conditions). Therefore, while steel bars provide the necessary tensile strength, concrete provides a perfect environment for the steel, acting as a physical barrier to the ingress of aggressive species and giving chemical protection in a highly alkaline environment (PH value is about 13.5), in which black steel is readily passivated.

LESS MAINTENANCE REQUIRED: Under normal conditions, concrete structures do not need coating or painting as protection for weathering, while for a steel or wooden structure, it is necessary. Moreover, the coatings and paintings have to be replaced few years. Thus, the maintenance cost for concrete structures is much lower than that for steel or wooden structures.

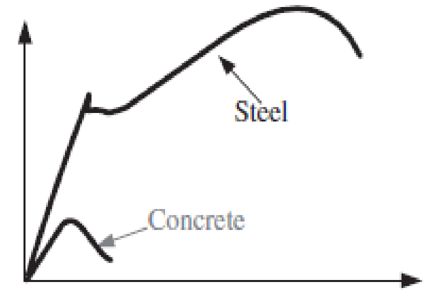
DESPITE BEING VERY ADVANTAGEOUS IN MANY ASPECTS, THE CONCRETE HAS SOME LIMITATIONS AS:

QUASI-BRITTLE FAILURE MODE: The failure mode of materials can be classified into three categories: brittle failure, quasi-brittle failure, and ductile failure. Glass is a typical brittle material. It will break as soon as its tension strength is reached. Materials exhibiting a strain-softening behavior (Figure 1-12b) are called quasi-brittle materials. Both brittle and quasi-brittle materials fail suddenly without giving a large deformation as a warning sign. Ductile failure is a failure with a large deformation that serves as a warning before collapse, such as low-carbon steel. Concrete is a type of quasi-brittle material with low fracture toughness.

CONTINUED……PROPERTIES OF CONCRETE :



(a)Brittle (b)Quasi-brittle (c)Ductile



1-13 Toughness of steel and concrete

Usually, concrete has to be used with steel bars to form so-called reinforced concrete, in which steel bars are used to carry tension and the concrete compression loads. Moreover, concrete can provide a structure with excellent stability. Reinforced concrete is realized as the second generation of concrete.

LOW TENSILE STRENGTH: Concrete has different values in compression and tension strength. Its tension strength is only about 1/10 of its compressive strength for normal-strength concrete, or lower for high-strength concrete. To improve the tensile strength of concrete, fiber-reinforced concrete and polymer concrete have been developed.

LOW TOUGHNESS (DUCTILITY): Toughness is usually defined as the ability of a material to consume energy. Toughness can be evaluated by the area of a load–displacement curve. Compared to steel, concrete has very low toughness, with a value only about 1/50 to 1/100 of that of steel. Adding fibers is a good way to improve the toughness of concrete.

LOW SPECIFIC STRENGTH (STRENGTH/DENSITY RATIO): For normal-strength concrete, the specific strength is less than 20, while for steel it is about 40. There are two ways to increase concrete specific strength: one is to reduce its density and the other is to increase its strength. Hence, lightweight concrete and high-strength concrete have been developed.

CONTINUED……PROPERTIES OF CONCRETE :

FORMWORK IS NEEDED: Fresh concrete is in a liquid state and needs formwork to hold its shape and to support its weight. Formwork can be made of steel or wood. The formwork is expensive because it is labor intensive and time-consuming. To improve efficiency, precast techniques have been developed.

LONG CURING TIME: The design index for concrete strength is the 28-day compression strength. Hence, full strength development needs a month at ambient temperature. The improvement measure to reduce the curing period is steam curing or microwave curing.

WORKING WITH CRACKS: Even for reinforced concrete structure members, the tension side has a concrete cover to protect the steel bars. Due to the low tensile strength, the concrete cover cracks. To solve the crack problem, pre-stressed concrete is developed, and it is also realized as a third-generation concrete. Most reinforced concrete structures have existing cracks on their tension sides while carrying the service load.

PROBLEMS RELATED TO THE TOPICS DISCUSSED :

ASSIGNMENT 1 :

1) Why is concrete so popular?
2) What are the weaknesses of concrete?
3) What are the factors influencing concrete properties?
4) Give some examples for concrete applications.
5) Can you list a few topics for concrete research?
6) When you do a structural design, which failure mode should be applied?
7) How would you like to improve concrete workability (fluidity or cohesiveness)?
8) How can you enhance concrete compressive strength?
9) Which principles are you going to follow if you are involved in a concrete research?

“Thank you”

Have Any Query ?

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