Chapter 01: **Concrete and steel as construction materials**

1. CONCRETE

Concrete, in construction is a material consisting of a hard, chemically inert particulate substance, known as aggregate (usually sand and gravel), that is bonded together by cement and water.

1.1 Production Process of Concrete:

A good quality concrete is essentially a **heterogeneous** mixture of **cement**, **coarse** and **fine** aggregates and **water** which consolidates into a hard mass due to **chemical action** between the cement and water. Each of the **four constituents** has a specific function. The coarser aggregate acts as a **filler**. The fine aggregate **fills up the voids** between the paste and the coarse aggregate. The cement in conjunction with water acts as a **binder**. The mobility of the mixture is aided bythe cement paste, fines and nowadays, increasingly by the use of **admixtures**.

Most of the properties of the hardened concrete depend on the care exercised at every stage of the manufacture of concrete. A rational proportioning of the ingredients of concrete is the essence of the **mix design**. However, it may not guarantee of having achieved the objective of the quality concrete work. The aim of quality control is to ensure the production of con crete of uniform strength from **batch to batch**. This requires some rules to be followed in the various stages of concrete production and is discussed as follows. The stages of concrete productionare:

1. Batching or measurement of materials
2. Mixing
3. Transporting
4. Placing
5. Compacting
6. Curing
7. Finishing

1. Batching of Materials

For good quality concrete a proper and accurate quantity of all the ingredients should be used. There are two prevalent methods of batching materials, the **volume batching** and the **weigh batching**. The factors affecting the choice of batching method are the **size of job**, required **production rate**, and required **standards of batching performance**. For most important works **weigh batching** is recommended.

a) Volume Batching
b) Weigh Batching

2. Mixing

- ➢ Hand Mixing
- ➢ Machine Mixing
- ➢ Tilting Mixers
- ➢ Non-tilting Mixer
- ➢ Reversing Drum Mixer
- ➢ Pan-type or Stirring Mixer
- ➢ Transit Mixer

2. **Transporting**

Concrete should be transported to the place of deposition at the earliest without the **loss of homogeneity** obtained at the time of mixing. A **maximum of 2 hours** from the time of mixing is permitted if **trucks with agitator** and **1 hour** if trucks **without agitators** are used for transporting concrete. Also it should be ensured that **segregation** does not take place during transportation and placement. The methods adopted for transporting concrete depend upon the **size and importance of the job**, the **distance of the deposition** place from the mixing place, and the **nature of the terrain**. Some of the methods of transporting concrete are as below:

- Mortar Pan
- Wheel Barrow
- Chutes
- Dumper
- Bucket and Ropeway
- Belt conveyor
- Skip and Hoist
- Pumping

4. Placing

To achieve quality concrete, it should be placed with utmost care securing the uniformity achieved during mixing and the avoidance of **segregation in transporting**. Research has shown that a delayed placing of concrete results in a gain in ultimate compressive strength provided the concrete can be adequately compacted. For **dry mixes in hot weather** delay of **half to one hour** is allowed whereas for **wet mixes in cold weather** it may be **several hours**. The various situations in which concrete is placed are discussed below.

- **Foundations (Sub Structure)**

Concrete foundations for walls and columns are provided below the ground surface.
Before placing the concrete in the foundation all the loose earth, roots of trees etc., are removed.
If the surface is found dry it is made wet so that earth does not absorb water from concrete. On the other hand if the foundation bed is wet the water and mud is removed and cement is sprinkled before placing concrete.

- **Beams, Columns, and Slabs (Super Structure)**

Before placing the concrete, the **forms** must be examined for correct alignment. They should be adequately rigid to withstand the weight of concrete and construction loads without undue deformation. Forms should be light enough to avoid any loss of mortar resulting in honeycombed concrete. The insides of the forms should be **cleaned** and **lubricated** (oiled) before use to avoid any **sticking** of concrete with the forms and making their **stripping** off difficult.

Concrete should not be **dropped** but placed in position to prevent **segregation**. It should be dropped vertically from as small height as possible. It should be placed at one point in the formwork and allowed to flow side ways to take care of honeycombing.

Laitance formation should be avoided. It can be checked by restricting thickness of layer of concrete by 150-300 mm for R.C.C work. Laitance, however, if formed must be removed before placing the next layer of concrete. Several such layers form a lift, provided they follow one another quickly enough to avoid cold joints. The surface of the previous lift is kept rough and all the laitance removed before placing the next lift.

The reinforcement should be checked for tightness and clean surface. The loose **rust or scales** if any, are removed by **wire brush**. Paint, oil or grease if found should be removed. The **minimum cover** for reinforcement should be checked before concreting.

- **Mass Concreting**

When the concrete is to be laid in mass as for raft foundation, dam, bridge, pier etc., concrete is placed in layers of **350-450 mm thickness**. Several such layers placed in quick succession form a lift. Before placing the concrete in the next lift, the surface of the previous lift is cleaned thoroughly with water jets and scrubbing by wire brush. In case of dams, sand blasting is done. The laitance and loose materials are removed and cement slurry is applied. When the concrete is subjected to lateral thrust, *bond bars* or *bond stones* are provided to form a key between different layers.

- **Concreting Highways and Runways**

Concrete is laid in bays for highway, runway, or floor slabs. First the ground on which concrete is to be laid is prepared and all the loose materials and grass etc., are removed. The earth is wetted and compacted. The subgrades over which concrete is to be laid should be properly compacted and damped to avoid any loss of moisture from concrete. Concrete is then laid in alternate bays. This allows the concrete to undergo sufficient shrinkage and cracks do not develop afterwards. Concrete is not placed in heap at one place and then dragged, instead it is placed in uniform thickness.

- **Concreting Underwater**

Concrete may be placed underwater with the help of bottom dump buckets. The concrete is taken through the water in water- tight bucket. On reaching the place of deposition the bottom of the bucket is made to open and the concrete is dumped. In this process certain amount of cement is washed away causing a reduction in strength of concrete. Another way of concreting underwater is by filling cement bag with dry or semi-dry mix of cement and aggregates and lowering them to the place of deposition. The drawback of this method is that the concrete will be full of voids interspersed with participle gunny bags.

The best method of placing concrete underwater is by the use of **termite pipe**. The concrete is poured into it through funnel. The bottom end of the pipe is closed with a thick ploythene sheet, with the bottom end of the pipe at the place of deposition. The concrete (slump 150-200 mm) is poured into funnel till the whole pipe is filled with concrete. The pipe is slightly lifted and given a jerk, the polythene sheet cover falls and concrete discharged. It should be ensured that the end of pipe remains inside the concrete so that water does not enter the pipe. The pipe is again filled with concrete through funnel and the process repeated till the concrete level comes above the water level.
No compaction is required for underwater concrete as it gets compacted by the hydrostatic pressure of water. Concrete can also be placed underwater with the help of pipes and pumps.

5. Compacting

After concrete is placed at the desired location, the next step in the process of concrete production is its compaction. Compaction consolidates **fresh concrete** within the **moulds** or **frameworks** and around embedded parts and reinforcement steel. Considerable quantity of **air is entrapped** in concrete during its production and there is possible **partial segregation** also.

Both of these adversely affect the quality of concrete. Compaction of the concrete is the process to get rid of the entrapped air and voids, elimination of segregation occurred and to form a uniform dense mass. It has been found that **5 per cent voids** in hardened concrete reduce the strength by over **30 per cent** and **10 per cent** voids reduce the strength by over **50 per cent**. Therefore, the **density** and consequently the **strength** and **durability** of concrete largely depend upon the degree **of compaction**. For maximum strength driest possible concrete should be compacted 100 per cent.

The **voids** increase the **permeability** of concrete. **Loss of impermeability** creates easy passage of moisture, oxygen, chlorides, and other aggressive chemicals into the concrete. This causes **rusting** of steel and **spalling** (disintegration) of concrete i.e., **loss of durability**. Easy entry of **sulphates** from the environment causes **expansive reaction** with the **tricalcium aluminate** (C_3A) present in cement. This causes **disintegration** of concrete and **loss of durability**. Entry of **carbon dioxide** causes **carbonation of concrete** i.e., **loss of alkalinity** of concrete or loss of the **protective power** that concrete gives to the reinforcement or other steel embedded in it. Once the **carbonation depth exceeds the thickness of concrete cover** to the embedded steel, steel becomes vulnerable to the attack of moisture. This expedites rusting of steel as the protective concrete cover remains no longer alkaline in nature.

Voids also reduce the contact between embedded steel and concrete. This results in loss of **bond strength** of reinforced concrete member and thus the member **loses strength**. **Voids** such as **honeycombs** and **blowholes** on the exposed surface produce visual blemish. Concrete surface is not good to look with all such blemishes. Concrete with smooth and perfect, surface finish not only looks good but is also stronger and more durable.

Compaction is achieved by imparting **external work** over the concrete to overcome the internal friction between the particles forming the concrete, between concrete and reinforcement and between concrete and forms and by reducing the air voids to a minimum. The compaction of concrete can be achieved by the following methods.

1. Hand Compaction
2. Compaction by Vibration
    a. Needle Vibrator:
    b. Formwork Vibrator
3. Compaction by Spinning
4. Compaction by Jolting
5. Compaction by Rolling

6. Curing

Cement gains strength and hardness because of the chemical action between cement and water. This chemical reaction requires moisture, favorable temperature and time referred to as the curing period. The variation of compressive strength with curing period is shown in Fig.10.11 (a, b). Curing of freshly placed concrete is very important for optimum strength and durability.

The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about three weeks. The later strength contributed by **C_2S** is gradual and takes long time. As such sufficient water should be made available to concrete to allow it to gain full strength. **The process of keeping concrete damp for this purpose is known as curing.** The object is to prevent the **loss of moisture** from concrete due to evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the **gain of strength**. Curing must be done for at least three weeks and in no case for less than ten days.

Approximately **14 liters of water is required to hydrate each bag of cement**. Soon after the concrete is placed, the increase in strength is **very rapid** (3 to 7 days) and continues slowly thereafter for an indefinite period. Concrete moist cured for 7 days is about 50 per cent stronger than that which is exposed to dry air for the entire period. If the concrete is kept damp for one month, the strength is about double than that of concrete exposed only to dry air.

- **Methods of Curing**

Concrete may be kept moist by a number of ways. The methods consist in either supplying additional moisture to concrete during early hardening period by ponding, spraying, sprinkling, etc. or by preventing loss of moisture from concrete by sealing the surface of concrete by membrane formed by curing compounds. Following are some of the prevalent methods of curing.

- Water Curing
- Steam Curing
- Curing by Infra-Red Radiation
- Electrical Curing
- Chemical Curing

7. Finishing

Concrete is basically used because of its high compressive strength. However, the finish of the ultimate product is not that pleasant. In past couple of decades efforts have been made to develop surface finishes to give a better appearance to concrete surfaces and are as follows.

- Formwork Finishes
- Surface Treatments
- Applied Finishes

2.2 Properties of Fresh Concrete:

Concrete remains in its fresh state from the time it is mixed until it sets. During this time the concrete is handled, transported, placed and compacted. Properties of concrete in its fresh state are very important because the influence the quality of the hardened concrete.
The fresh concrete has the following procedure.

1. **Consistency**
2. **Workability**
3. **Settlement & Bleeding**
4. **Plastic shrinkage**
5. **Loss of consistency**

2.3 Mechanical properties of concrete

Performance of concrete is evaluated from mechanical properties which include shrinkage and creep, compressive strength, tensile strength, flexural strength, and modulus of elasticity.

- ***Shrinkage and Creep***

When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called instantaneous strain. Now, if the load is maintained for a considerable period of time, concrete undergoes additional deformations even without any increase in the load. This time-dependent strain is termed as **creep**. Shrinkage is the **reduction in the volume** of hardened concrete due to **loss of moisture** by **evaporation**.

There are several similarities and dissimilarities between creep and shrinkage. First, the source for both the effects are the same, which is **loss of adsorbed moisture** from the hydrated cement paste. In shrinkage, the loss is due to difference in the relative humidity of concrete and the environment, in creep it is due to sustained applied stress. Second, the **strain-time** curves of both the phenomenon are very similar.

The factors that affect creep also effects shrinkage. They both increase with: higher cement content, higher water content, lower aggregate content, low relative humidity, high temperature, small thickness of the member, etc.

- ***Compressive strength***

Compressive strength is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture. The formula for calculating compressive strength is: CS = F / A

Where in compressive strength (CS) is equal to the force (F) at the point of failure divided by the cross sectional area. Compressive strength tests must be performed with equal opposing forces on the test material. Test materials are normally in cylinders, cubes or spheres.

- ***Tensile strength***

Tensile strength, maximum load that a material can support without fracture when being stretched, divided by the original cross-sectional area of the material. Tensile strengths have dimensions of force per unit area and in the English system of measurement are commonly expressed in units of pounds per square inch, often abbreviated to psi. When stresses less than the tensile strength are removed, a material returns either completely or partially to its original shape and size. As the stress reaches the value of the tensile strength, however, a material, if ductile, that has already begun to flow plastically rapidly forms a constricted region called a neck, where it then fractures.

- ***Flexural strength***

The flexural strength of a material is defined as the maximum bending stress that can be applied to that material before it yields. The most common way of obtaining the flexural strength of a material is by employing a transverse bending test using a three-point flexural test technique. Flexural strength is also known as bending strength, modulus of rupture or transverse rupture strength.

Modulus of elasticity

The ratio of the stress in a body, to the corresponding strain.

Quality Tests on concrete

Each quality test conducted on concrete determines their respective quality result of concrete. Hence, it is not possible to conduct all the test to determine the quality of concrete. We have to choose the best tests that can give good judgment of the concrete quality. The primary quality test determines the variation of the concrete specification from the required and standard concrete specification. The quality tests ensure that the best quality concrete is placed at the site so that concrete structural members of desired strength are obtained. Below mentioned are the quality tests conducted on fresh and hardened concretes.

a- Fresh Concrete

Most Common Quality Tests on Fresh concrete are:

1. *Workability Tests*

Workability of concrete mixture is measured by, Vee-bee consistometer test, Compaction factor Test, and Slump test.

2. *Air content*

Air content measures the total air content in a sample of fresh concrete but does not indicate what the final in-place air content is, because a certain amount of air is lost in transportation Consolidating, placement, and finishing.

3. Setting Time

The action of changing mixed cement from a fluid state to a solid state is called “Setting of Cement”. **Initial Setting Time** is defined as the period elapsing between the time when water is added to the cement and the time at which the needle of 1 mm square section fails to pierce the test block to a depth of about 5 mm from the bottom of the mold. **Final Setting Time** is defined as the period elapsing between the time when water is added to cement and the time at which the needle of 1 mm square section with 5 mm diameter attachment makes an impression on the test block.

Other tests conducted on fresh concrete are:

1. Segregation resistance
2. Unit weight
3. Wet analysis
4. Temperature
5. Heat generation
6. Bleeding

b- Hardened Concrete

Most Common Quality Tests on hardened concrete are:

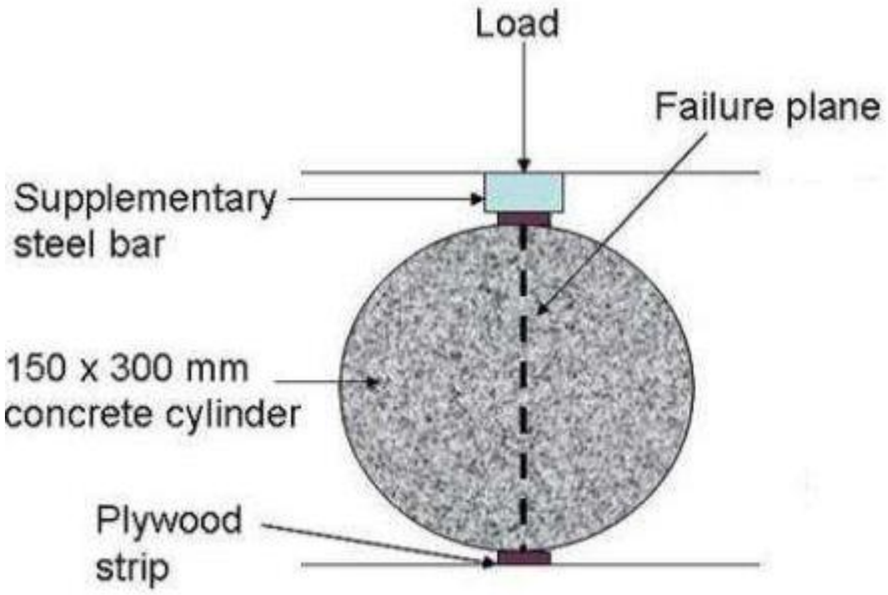
1. Compressive strength (MECHANICAL PROPERTY**)**

The compressive strength of concrete cube test provides an idea about all the characteristics of concrete. Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates.

Compressive Strength = Load / Cross-sectional Area

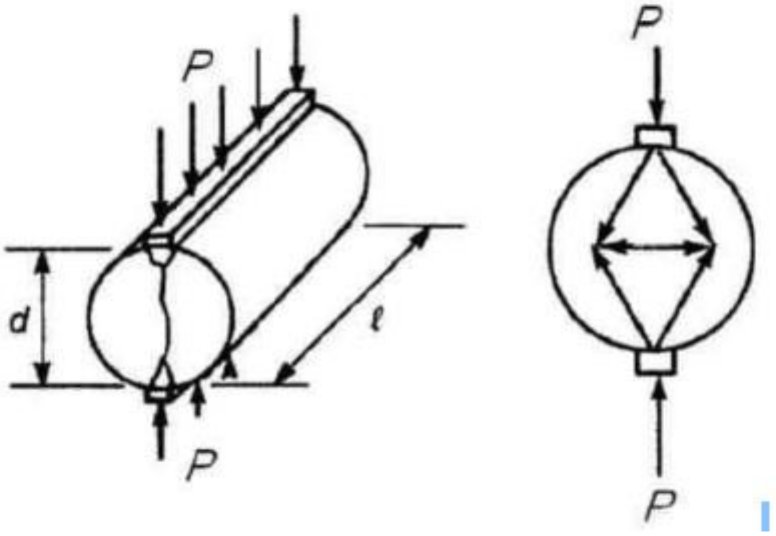
2. **Tensile strength (MECHANICAL PROPERTY)**

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. Moreover, the concrete is very weak in tension due to its brittle nature. Hence. It is not expected to resist the direct tension. So, concrete develops cracks when tensile forces exceed its tensile strength. Therefore, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. Furthermore, splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The procedure based on the ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) which similar to other codes like IS 5816 1999.



Calculations

Calculate the splitting tensile strength of the specimen as follows: T= 2P/ pi LD Where: T = splitting tensile strength, MPa P: maximum applied load indicated by the testing machine D: diameter of the specimen, mm L: length of the specimen, mm.



3. Modulus of elasticity (MECHANICAL PROPERTY)

Modulus of elasticity of concrete is defined as the ratio of stress applied on the concrete to the respective strain caused. The accurate value of modulus of elasticity of concrete can be determined by conducting a laboratory test called compression test on a cylindrical concrete specimen.
In the test, the deformation of the specimen with respect to different load variation is analyzed.

These observations produce Stress-Strain graph (load-deflection graph) from which the modulus of elasticity of concrete is determined. The slope of a line that is drawn in the stress-strain curve from a stress value of zero to the compressive stress value of 0.45f'ck (working stress) gives the modulus of elasticity of concrete.

2.4 Durability Property

a) ***Permeability Tests on Concrete***

When concrete is permeable it can cause corrosion in reinforcement in presence of oxygen, moisture, CO_2, SO_{3^-} and Cl -etc. This **formation of rust** due to **corrosion** becomes nearly **6 times the volume of steel oxide layer**, due to which cracking develops in reinforced concrete and spalling of concrete starts.

The durability of concrete structures depends on the permeability of reinforcement cover by concrete. It is this thin layer of concrete over reinforcement on which life of a structure depends. The **permeability tester** for concrete cover is a **non-destructive instrument** for the determination of **air permeability** of cover concrete. The permeability of concret cover depends on the condition of concreting at site such as segregation and bleeding, finishing and curing, the formulation of micro-cracks, etc. The composition and properties of the cover concrete may differ very considerably from those of the good quality of cover concrete. In addition, the concrete test specimens used for quality controls can never represent the quality and properties of the cover concrete since they are produced and stored in a completely different manner. Durability of concrete structure under aggressive environmental influences depends essentially on the quality of a relatively thin surface layer (20 – 50 mm). This layer is intended to protect the reinforcement from corrosion which may occur as a result of carbonation or due to ingress of chlorides or other chemical effects. The influence mentioned is enhanced by damage due to frost/thaw or frost/thaw/salt. There is no generally accepted method to characterize the pore structure of concrete and to relate it to its durability. However, several investigations have indicated that concrete permeability both with respect to air and to water is an excellent measure for the resistance of concrete against the ingress of aggressive media in the gaseous or in the liquid state and thus is a measure of the potential durability of a particular concrete. There is at present no generally accepted method for a rapid determination of concrete permeability and of limiting values for the permeability of concrete exposed to different environmental conditions. The Permeability Tester permits a rapid and non-destructive measurement of the
quality of the cover concrete with respect its durability. The general arrangement of the permeability tester is shown in fig below:

b) ***Acid Attack***
Acid resistance of concrete was determined in terms of **weight loss** and residual compressive strength. For this test, concrete cubes of size 150 mm x 150 mm x 150 mm were cast and stored in a place at a temperature of 27°C for 24 hrs and then the specimens were water cured for 28 days.

c) ***Sulphate attack***
As regards chemical reactions, the only test that indirectly determines the resistance of a cement to sulfate is **ASTM C 1012** through measuring the **expansion** of a specimen immersed in a sulphate solution (usually sodium sulfate. This test requires measurements for 6 months to a year.

d) **Chloride attack:**
When considering durability of concrete, chloride attack is the most imminent enemy. It is responsible for almost 40% of failure of concrete structures. In the presence of **oxygen and water**, chloride attack corrodes the steel reducing the strength of the structure drastically

e) ***Sorptivity***:
Ability of concrete to **absorb and transmit** water through it via **capillary suction** and provides an engineering measure of microstructure)

f) ***RCPT***
Rapid chloride permeability test): Used to determine the resistance to **penetration** of **chloride ions**
g) ***Water permeability test:***
determines the resistance of concrete against water under hydrostatic pressure

Curing
It should be clear from what has been said above that the detrimental effects of storage of concrete in a dry environment can be reduced if the concrete is adequately cured to prevent excessive moisture loss.

3. CONCRETE ADMIXTURES

They are **natural or manufactured chemicals or additives added during concrete mixing** to enhance specific properties of the fresh or hardened concrete, such as workability, durability, or early and final strength.

a Chemical Admixtures:
In general, seven chemical admixture types. They are:

- Type A: Water-reducing admixtures:
- Type B: Retarding admixtures
- Type C: Accelerating admixtures
- Type D: Water-reducing and retarding admixtures
- Type E: Water-reducing and accelerating admixtures
- Type F: Water-reducing, high range admixtures
- Type G: Water-reducing, high range, and retarding admixtures

b *Mineral Admixtures:*
Mineral admixtures make mixtures more economical, reduce permeability, increase strength, and influence other concrete properties. Mineral admixtures affect the nature of the hardened concrete through hydraulic or pozzolanic activity. Pozzolans are cementitious materials and include natural pozzolans (such as the volcanic ash used in Roman concrete), fly ash and silica fume. They can be used with Portland cement, or blended cement either individually or in combinations

Types of Admixtures (according to function) There are five distinct classes of chemical admixtures:

- **Air-Entraining Admixtures:**
- **Water-Reducing Admixtures:**
- **Retarding Admixtures:**
- **Accelerating Admixtures:**
- **Plasticizers** (Superplasticizers):