CHAPTER 03

Concrete

The cement concrete is a mixture of cement, sand, pebbles or crushed rock and water which, when placed in the skeleton forms followed by curing becomes hard like a stone.

1. Concrete is a composite man made material and is most widely used building material in the construction industry.
2. It is a mixture of binding material such as lime or cement, well graded coarse and fine aggregate water and sometime admixtures.
3. Most of the ancient structures and historical buildings had been constructed with Lime concrete but with the invention of cement, use of Lime concrete is limited in making bases of concrete foundations and roof terracing.
4. Basic requirement of Good concrete is that it should have good strength in hardened state and remain "fresh" plastic during transportation, placing, compaction.
5. In fresh state, consistency of mix should be such that it can be compacted by the desired means without excessive effort and also the mix should be cohesive enough for the methods of transporting and placing used so as not to cause segregation.

3.1 Properties of Cement Concrete

1. High compressive strength
2. Free from corrosion and there is no appreciable effect of atmospheric agents on it.
3. It hardens with age and the process of hardening continues for a long time.
4. It is proved to be more economical than steel.
5. It binds rapidly with steel and as it is weak in tension, the steel reinforcement is placed in cement concrete at suitable places to take up the tensile stresses. This is termed as the reinforced cement concrete or simply RCC.
6. It has a tendency to shrink.
7. It forms a hard surface, capable of resisting abrasion.

3.2 Classification of Concrete

1. Based on Cementing Material.

   (a) Lime concrete (b) Gypsum concrete (c) Cement concrete

2. Based on grade of cement concrete
3. Base on Bulk density

Extra light weight	< 500 kg/m^3
Light weight	500 – 1800 kg/m^3
Dense weight	1800 – 2500 kg/m^3
Super heavy weight	> 2500 kg/m^3

4. Based on place of casting
   (a) In-situ concrete: When concrete is placed in position at the site it is known as In-situ concrete.
   (b) Precast concrete : When concrete is used for making prefabricated units in a factory is called as precast concrete.

3.3 Manufacturing of Concrete

A. Batching:

1. Aggregates, cement and water should be measured with an accuracy of ± 3 per cent of batch quantity and the admixtures by 5 per cent of the batch quantity.
   There are two prevalent methods of batching materials are:
   (a) Volume batching
   (b) Weight batching
2. For most important works weight batching is recommended whereas, volume batching is generally recommended for small jobs only.

Volume Batching:

- Amount of each solid ingredient is measured by loose volume (not compacted).
  Example, volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand.
- Therefore correction for bulking of sand is done if volume batching is adopted.

Weight Batching:

- Cement is always measured by weight, irrespective of method of batching.
- Water is measured in kg or liters where density of water is 1 gm/cm^3.
- Volume of 1 bag of cement is 0.035 m^3 (or sometime also said 35 liters)

B. Mixing:

- Objective of mixing is to obtain homogenous, uniform colour and consistent concrete of desired strength.
- Mixing time depends on the type and capacity of mixer but IS-456 suggest approximately mixing time as 2 minutes.
- Generally 20 revolution of concrete in mixture provides sufficient mixing.
- If mixing time is increased upto 2 minutes the compressive strength of concrete produced is enhanced and beyond this time the improvement in compressive strength is insignificant and prolonged mixing may cause segregation as due to longer mixing periods the water may get absorbed by the aggregates or evaporate resulting in loss of workability and strength.
- The mixing is done in two ways i.e. 1. Hand mixing and 2. Machine mixing (mixture)

Hand Mixing:

- Hand mixing is adopted for small jobs where the quantity of concrete involved is small and the approximate time is 2 minutes should never exceed 3 minutes.

Machine Mixing:

- When a large quantity of concrete of the desired quality is to be produced, the machine mixing becomes imperative as Concrete can be produced at a faster rate with better quality.
- Concrete mixers are specified by the volume of mixed concrete discharged after mixing of each batch expressed in m^3 (such as 0.25, 0.38, 0.57, 0.75, 1.5, 2.25 and 3 m^3).
- Sometimes the total volume of the unmixed ingredients in m^3 is given as a prefix. i.e. 1.0/0.75 mixer takes 1 m^3 of unmixed material and gives 0.75 m^3 of mixed concrete in each batch.
- The machine mixing is done by using 1. Tilting type mixture, 2. Non tilting type mixture, 3. Batching plant.

1. Tilting type mixture:
   - In this mixed concrete is discharged by tilting the drum about the horizontal axis.
   - Tilting mixers are useful for large construction works.
   - It gives better results even will dry concrete.
   - It can be used for aggregate size more than 75 mm.
   - Tilting mixers are easier to clean and can discharge the mix quickly and with minimum segregation.
   - The tilting type mixtures are represented as 85T, 100T, 140T, 200T (where 85, 100, 140 are in litres.)
2. Non-tilting type mixture:
   - Non-tilting mixers are suitable for small works.
   - Non-tilting mixer is equipped with a drum rotating about a horizontal axis.
   - Non-tilting mixers cannot be used when aggregate size more than 75 mm.
   - Non-tilting mixers are represented as 200 NT, 280 NT, 340 NT, 400 NT, 800 NT.

NOTE

Sometimes the mixers are specified by two quantities the total volume of ingredients added and the volume of concrete produced for example 285/200-litres mixer takes 285 litres of ingredients and yields 200 liters of concrete.

C. Transportation:

- Specification states that the process of mixing transporting placing and compacting the concrete should not take more than initial setting time of cement (30 minutes using OPC)
- It must also ensure that segregation not took place.
- The transporting of concrete can be done by following methods.
  1. Pans: Recommended only for small jobs.
  2. Power Buggies: These have sped up to 24 km/h.
  3. Chutes : When concrete is to be deposited below ground level at a higher depth, it can be discharged through a steel shaft called chute.

4. **Concrete Pumps:** It is used commonly for tunnel works and on locations which are not easily accessible where concrete can be pumped for a distance of about 400 m. horizontally and 80 m vertically having slump value 50 mm to 100 mm and the pipe used in concrete pump having diameter 10 cm to 20 cm.
5. **Transit Mixer:** Transit mixer is a truck on which a concrete mixer is mounted and useful in built-up areas.
6. **Belt-conveyer:** A belt conveyer is used when the concrete is to be transported continuously and to an inaccessible area.

D. **Placing:**

- Research has shown that 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.
- As per IS456 maximum permissible free fall of concrete may be taken as 1.5 m

E. **Compaction:**

- The process of removal of entrapped air and of uniform placement of concrete to form a homogeneous dense mass is termed compaction.
- The density and consequently the strength and durability of concrete depends upon the quality of compaction.
- **The presence of even 5% and 10% voids in hardened concrete left due to incomplete compaction may result in a decreases in compressive strength by about 30% and 60% respectively.**

The various types of vibrators used are:

1. **Internal Vibrators**
   - These vibrators consist of a metal rod which is inserted in fresh concrete.
   - Skilled and experienced men should handle internal vibrators. These vibrators are more efficient than other types of vibrators.
   - These vibrators can compact upto 450 mm from the face but have to be moved from one place to another as concrete progresses.
   - The frequency of vibration is about 4000 to 12000 rpm.
   - The needle diameter varies from 20 mm to 75 mm and its length 25 cm to 90 cm.
2. **Surface Vibrators**
   - These vibrators are mounted on platform or screeds.
   - They are used to finish concrete surfaces such as bridge floors, road slabs, station platform, etc.
   - It is placed directly on the concrete mass for the compaction of shallow elements (where internal vibrators cannot be applied) i.e. depth ≯ 150 mm. Ex: Road surfaces, plain concrete floors etc.
3. **Form Vibrators or Shutter Vibrators**
   - These vibrators are attached to the formwork and external centering of walls, columns, etc. The vibrating action is conveyed to concrete through the formwork during transmission of vibrations. Hence they are not generally used.
   - But they are very much helpful for concrete sections which are too thin for the use of internal vibrators.
4. **Vibrating Tables**
   - It is very efficient in compacting stiff and harsh concrete mixes required for the manufacture of precast elements.

F. **Curing**

- The test specimens should be stored in a place free from vibration in most air of at least 90% relative humidity and at a temperature of 24 – 30°C for 24 hours from the time of addition of water to the dry ingredients.
- After this period the specimens are marked and removed from the moulds and unless required for test within 24 hours immediately submerged in clean fresh water kept there until taken out just prior to test.
- The specimens are not to be allowed to become dry at any time until they have been tested.
- Cement gains strength and hardness because of the chemical action between cement and water.
- The water in a concrete mix takes one of the following three forms as a consequence of hydration are:
  1. **Combined water:** Which combined with hydration products (C_3A, C_3S, C_4AF) its not evaporable.
  2. **Gel water:** The water prevails over cement Gel Surface Area.
  3. **Capillary water:** Which "occupy capillary pores" (Evaporable).
- Increase in strength of concrete is very rapid from 3 to 7 days and continues slowly for indefinite period.
- It has observed that moist cured concrete for 7 days is nearly 50% stronger than that which is exposed to dry air for entire period.
- If concrete is cured for one month, strength is nearly double than that of concrete exposed to dry air.

Objective of Curing:

- **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.**
- To keep capillary pores saturated to ensure hydration of cement; to increases durability, impermeability of concrete and reduce the shrinkage.
- As per IS: 456 concrete members shall be kept under curing for a **minimum period of 7 days for OPC at 90% humidity** and atleast 10 days where **mineral admixtures and blended cements are used.**

NOTE: Lower temperature reduces the rate of setting and higher temperature reduces the ultimate strength. Therefore curing temperature need to be within 5 to 30°C.

Steam Curing:

- For concrete mixes with water cement ratio ranging from 0.3 to 0.7 the increased rate of strength development can be achieved by resorting to steam curing.
- This method of curing is also known as accelerated curing since an increased rate of strength development can be achieved.

- Concrete members are heated by steam at 93°C either at low pressure or high pressure.
- **By low pressure steam curing about 70 per cent of the 28 day compressive strength of concrete can be obtained in about 16–24 hours and high pressure steam curing is usually applied to precast concrete members and gives 28 day compressive strength at 24 hours.**
- **It reduces shear strength of concrete.**
- It also results in increased resistance to sulphate action and to freezing and thawing.
- Rate of increase or decrease of temperature should not exceed 10 to 20°C per hour to avoid thermal shocks.
- "Infra Red Radiation" is also helpful method of curing for Rapid Gain of Strength.

G. Finishing:

- Finishing is defined as the process of levelling and smoothing the top surface of freshly placed concrete to achieve the desired appearance is done by as follows:
  1. **Screeding:** Striking off the excess concrete to bring the top surface up to proper grade is called screeding.
  2. **Troweling:** Final operation of finishing be doe after all excess water has evaporated by steel float in conical shape giving a very smooth finish.

Maturity of Concrete

- The strength of concrete depends on both period of curing (i.e. age) and temperature during curing.
- The product (period × temperature) is called the maturity of concrete
- It is measured in °C hours to °C days.

3.4 Materials Used in RCC work

1. Cement
2. Aggregates (both coarse and fine)
3. Steel
4. Water

Do You Know?

- The hyrib which is a steel lath may also be used as steel reinforcement.
- The water, which is used for making concrete, should be clean and free from harmful impurities such as oil, alkali, acid, etc. In general, the water which is fit for drinking should be used for making concrete.

3.5 Different Methods of Proportioning Concrete

1. Nominal Mix
   - In this method, there is no rigid control on the strength of the concrete mix. However this method is widely used for all works of small magnitude because of its simplicity in the design. Therefore, the following table need to be considered by doing nominal mix.
   - When the proportions of cement, aggregate and water are adopted based on any arbitrary standard, the concrete produced is termed as nominal mix concrete.
   - Nominal mix concrete is used in works where the quality control requirement for design mixes are difficult to be implemented. Nominal mix concrete can be produced by taking cement, fine and coarse aggregate in the ratio of 1 : n : 2n for normal work. However, the ratio of the coarse aggregate to fine aggregate can vary from 1.5 : 2.5 in situations where denser or more workable concrete is to be produced.

Proportion of concrete mix	Maximum size of aggregate	Nature of work
1:1:2	12 to 20 mm	Heavily loaded RCC columns and RCC arches of long span.
1:2:2	12 to 20 mm	Small precast members of concrete such as poles for fencing telegraphs. etc. long piles. watertight constructions and heavily stressed members of the structures.
1:1.5:3	20 mm	Water retaining structures, piles, precast products, etc.
1:2:3 or 1:3.66:3.33	20 mm	Water tanks, concrete deposited under water, bridge construction and sewers.
1:2.5:3.5	25 mm	Footpaths and road work.
1:2:4	40 mm	For all general RCC works in building such as stair, beam, column, weather shed, slab, lintel, etc., machine foundations subjected to vibrations and RCC piles.
1:3:6	50 mm	Mass concrete work in culverts, retaining walls, etc.
1:4:8 or 1:5:10 or 1:6:12	60 mm	Mass concrete work for heavy walls, foundation footings, etc.

Do You Know?

For general guidance, the nominal mixes correspond approximately to the different grades as follows:

M5	:	1 : 5 : 10	M7.5	:	1 : 4 : 8
M10	:	1 : 3 : 6	M15	:	1 : 2 : 4
M20	:	1 : 1½ : 3	M25	:	1 : 1 : 2

- In order to get a concrete of minimum voids the quantity of fine aggregate completely fills the voids of the coarse aggregate and the quantity of cement should completely fills the voids of the fine aggregate.
- The sufficient water is added to the mix of cement fine aggregate and coarse aggregate to make the mix workable.
- In this method the grading cannot be accurately achieved and there is no control over the strength of concrete.

2. Design Mix
   - When the task of deciding the proportion of the constituents of concrete is accomplished by use of certain established relationships (which are based on inferences drawn from a large number of experiments) the concrete thus produced is termed as design mix concrete.
   - For RCC work, the maximum size of aggregates is limited to 20-25 mm.
   - For a concrete of given workability, rounded aggregates require least water-cement ratio. Particle shape is very important since the water cement ratio governs greatly the strength of concrete.

     Coarse aggregates > 4.75 mm size.

     Fine aggregates < 4.75 mm size.

3.5.1 IS Code Method of Concrete Mix Design

Concrete mix design procedure for a particular grade of concrete depends on the following requirements:

1. Characteristic strength of concrete (f_{ck}) required.
2. Degree of workability required.

3. Specific gravity and bulk density of cement.
4. Grading zone of fine aggregate (sand) and size of coarse aggregates.
5. Specific gravity and bulk density of coarse and fine aggregates.
6. Moisture content i.e. water absorption of coarse and fine aggregates.

3.6 Steps for Concrete Mix Design as per IS Code Method

IS 10262 : 2009 gives guidelines for concrete mix proportioning.

Step-1: Target mean strength and standard deviation

- Cubes made of same concrete show slightly different strengths. IS 456 : 2000 recommends that standard deviation for each concrete grade should be determined separately. Further, it states that not less than 30 samples are to be tested.
- In the absence of sufficient test result, Table 1 of IS 10262 : 2009 and also IS 456 : 2000 suggests the following standard deviation:
- The target mean strength is then determined as,

$$f_{ck}' = f_{ck} + kS$$

Where S = Standard deviation

k = A constant which is as per IS code is 1.65

The target mean strength

$$f_{ck}' = f_{ck} + 1.65\ S$$

Step-2: Selection of water-cement ratio

- Cl. 4.1 of IS 10262 : 2009 specifies guidelines for selection of water cement ratio. For the same water-cement ratio, the strength of concrete obtained may be different because of difference in the cement quality and difference in shape, size and grade of aggregate.
- It is important to establish the relationship between water-cement ratio and strength of concrete. In the absence of this relationship, Table 5 of IS 456 : 2000, gives free water-cement ratio for different grades of concrete.

Table : Maximum free water-cement ratio v/s minimum grade of concrete.

Exposure	Plain concrete		Reinforced concrete	
	Max. free w/c ratio	Min. concrete grade	Max. free w/c ratio	Min. concrete grade
Mild	0.6	—	0.55	M20
Moderate	0.6	M15	0.5	M25
Severe	0.5	M20	0.45	M30
Very severe	0.45	M20	0.45	M35
Extreme	0.40	M25	0.40	M40

Step-3: Selection of water content

- Cl. 4.2 of IS 10262 : 2009 states about selection of water content. Table 2 of IS 10262 : 2009 gives maximum water content per cubic meter of concrete for angular coarse aggregates and for 25-50 mm slump.
- Water content as arrived at corresponds to saturated and surface dry aggregates.

Connections:

- The so computed maximum water content is reduced if aggregates used are:
  Sub angular aggregates – 10 kg/m^3
  Gravel with certain crushed particles – 20 kg/m^3
  Rounded gravels – 25 kg/m^3
- For slump of than 25-50 mm, increase the water content by 3% for each additional 25 mm slump.

Step-4: Calculation of cementations material content

- Cl. 4.3 of IS 10262 : 2009 recommends to compute the cement and supplementary cementations material content per unit volume of concrete from free water-cement ratio i.e.,

$$\text{Cementations material, } C = \frac{\text{Water content used}}{\text{Water-cement ratio}}$$

- From durability considerations, the above computed value of cementations material (C) should not be less than the values as given in Table.

Table : Maximum cement content for normal weight aggregates of 20 mm

Exposure	Plain concrete (kg/m^3)	Reinforced concrete (kg/m^3)
Mild	220	300
Moderate	240	300
Severe	250	320
Very severe	260	340
Extreme	280	360

Table : Adjustment to cement content

Nominal size of aggregate (mm)	Adjustment to minimum cement content
10	+ 40 kg/m^3
20	0
40	– 40 kg/m^3

Step-5: Estimate of coarse aggregates

- Cl. 4.4 of IS 10262 : 2009 states about the estimation of coarse aggregates per unit volume of concrete. Table 3 of IS 10262 : 2009 gives volume of coarse aggregates per unit volume of concrete for different zones of fine aggregates.

Table : Volume of coarse aggregates per unit volume of concrete (for different zones of fine aggregates (i.e., sand)

Nominal max. size of aggregate (in mm)	Volume of coarse aggregates per unit volume of concrete for different zones of find aggregates (kg/m^3)			
	Zone-1	Zone-2	Zone-3	Zone-4
10	0.50	0.48	0.46	0.44
20	0.66	0.64	0.62	0.60
40	0.75	0.73	0.71	0.69

The above value are based on saturated and surface dry aggregates condition.

Step-6: Estimation of mass of coarse aggregates

- After arriving at the masses of cement and water, the volume of total aggregate is computed as:

$$V_A = 1-\left[\frac{C}{S_c}+\frac{W}{1}\right]\times\frac{1}{1000}$$

where C = Mass of cement; S_c = Specific gravity of cement, W = Mass of water

- If other materials like fly ash, chemical admixtures are also added, air-entrainment is also incorporated then the volume of all these materials must be subtracted from unity in order to get the volume of total aggregates as,

$$V_A = 1-\left[\frac{C}{S_c}+\frac{W}{1}+\frac{F}{S_f}+\frac{P}{S_p}\right]\times\frac{1}{1000}-v$$

where F = Mass of fly ash, P = Mass of plasticizer, S_f = Specific gravity of fly ash

S_p = Specific gravity of plasticizer, v = Volume of entrained air (in fraction)

- From the percentage of coarse aggregate (p) as found in step 5 above, the mass of coarse aggregate is computed as:

Mass of coarse aggregate

$$= pV_AS_{CA}\times 1000$$

where, S_{CA} = Specific gravity of coarse aggregate

Similarly, mass of fine aggregate is given by,

Mass of fine aggregate $= (1-p)\,V_AS_{FA}\times 1000$

where, S_{FA} = Specific gravity of fine aggregate

Step-7: Correction for actual site conditions

- Often the available coarse and fine aggregates available at site are not in saturated and surface dry conditions.
- If there is some moisture content already present in the free state then reduce the amount of water required to that extent and increase the amount of aggregate by the same extent.
- If aggregates absorb moisture then definitely it will pose a deficiency in water required for concrete. So increase the water content by that extent and decrease the mass of aggregate by the same extent.

3.6.1 Fineness Modulus of Aggregate

The term fineness modulus is used to indicate an index number which is roughly proportional to the average size of the particle in the entire quantity of aggregate.

Let p be the designed fineness modulus for a concrete mix of fine and coarse aggregates.

Then $$R = \frac{p_2-p}{p-p_1}\times 100$$

where R = proportion of fine aggregate to the combined aggregate by weight

p_1 = fineness modulus of fine aggregate

p_2 = fineness modulus of coarse aggregate

Table: Assumed Standard Deviation

Grade of concrete	Assumed standard deviation (N/mm^2)
M10, M15	3.5
M20, M25	4.0
M30 to M55	5.0

3.6.2 Fineness Modulus

- The fineness modulus of an aggregate is an index number which is roughly proportional to the average size of the particles in the aggregate. The coarser the aggregate, the higher is the fineness modulus.
- Fineness modulus is obtained by adding the percentage of the weight of the material retained on a total of 10 numbers of IS sieves (of sieve opening between 80 mm to 150 μm) and dividing it by 100.

3.7 Durability of Concrete

- A durable concrete is one that performs satisfactorily under anticipated exposure conditions for its stipulated life.
- Various factors affecting durability of concrete are as follows:

1. Permeability
   - Ingress of water leads concrete susceptible to chemical attack, forest action, rusting of steel etc.
   - We can reduce permeability by
     (i) Providing high grade of concrete
     (ii) Using well-graded dense aggregate
     (iii) Using low water-cement ratio, adequate cement and effective curing.
     (iv) Using appropriate admixtures
     (v) Achieving maximum compaction
     (vi) The above parameter is giving thrust to the concrete of Dense Mix to reduce Permeability.
2. Frost action
   - The Le Chatelier's
   - Concrete is be affected due to being permeable or by temperature below 0°C.
   - Because of expansion of absorbed water on freezing ice builds up in large pores causing large expansion in local areas the others being dry cause disintegration.
   - Low temperatures increasing the extent of migration of water resulting in freezing to greater depths in the concrete.
3. Sulphate attack
   - Sulphate attack is a chemical reaction between the products of hydration of cement and solution containing sulphate of calcium, Magnesium and sodium (water).
   - These sulphates reacts with C_3A and formed calcium sulphoaluminate (ettringite) which expands and causes disruption of concrete.
   - Magnesium sulphate has the most severe discriptive action.
   - Common source of sulphate salts is the soil around the concrete foundation is from the water used in making concrete, and by using unwashed aggregates.
   - It can be reduced by use of blast furnace slag cement, sulphate resisting cement supersulphated cement, and by reducing the permeability.
4. Organic Acids
   - Acetic acid, lactic acid, and butyric acid severally attack concrete.
5. Sugar (Retarder)
   - It is a retarding agent and gradually corrodes concrete if added in excess as a admixture.

3.8 Defects in Concrete

1. Cracks
   - Cracks are inherent in concrete and cannot be completely prevented but can be minimized.

   The reasons for cracks in a concrete are:

   (a) excess water

   (b) early loss of water

   (c) Alkali aggregate reaction

   (d) Freeze and thawing

2. Efflorescence
   - It is appearance of fluffy white patches on the surface of concrete members.
   - It is caused by poorly washed aggregate, salty water used in making concrete the salts being leaching out to the surface by rain water afterwards on evaporation while patches appear on the surface.

3. Segregation
   - It is separation of (a) coarse aggregate from fine aggregate, (b) paste from coarse aggregate, or water from the mix and the ingredients of the fresh concrete no longer remain uniformly distributed.
   - It can be reduced by increasing small size coarse aggregate, air entrainment, using dispersing agents and puzzolona.
   - Causes of segregation are excess water, dropping concrete from heights, badly designed mixes, concrete carried over long distances excess water-pumping, belt conveyor system etc. over vibrations and during concrete finishing extra floating and tamping.

4. Bleeding
   - It is an flow of mixing water within or emergence to the surface from freshly placed concrete is usually due to excessive vibrations imparted to concrete to achieve full compaction.
   - Bleeding can be reduced by the use of uniformly graded aggregates, puzolona – by breaking the continuous water channel or by using – entraining agents, finer cement and a rich mix.

3.9 Physical Proportions of Concrete

1. Stress strain curve
   - Stress strain curve of concrete in compression shown in figure.
   - Since mortar and concrete have no elastic limit, the modulus of elasticity for concrete must be the slope of the stress deformation curve at zero stress.
   - Elastic modulus of concrete in compression, $E_c = 5000\sqrt{f_{ck}}$, where f_{ck} is the characteristic strength of concrete.
   - Elastic modulus of concrete increases with the density, compressive strength and to some extent with age.

2. Poison's ratio
   - It is determined as the ratio of lateral to longitudinal strain in compression test and vary from 0.1 to 0.3.

3. Creep
   - It is continued deformation with time under a constant load, it is also known as plastic flow or time yield.
   - Rate of creep decrease with time and the creep strains at five years are taken as terminal values. It increases rapidly with the stress, loading at an early age of concrete.

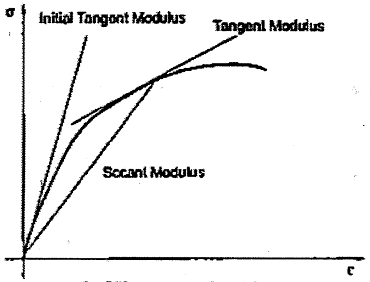


Fig. Different types of modulus of elasticity in the stress-strain curve

3.10 Water-cement Ratio

The water in concrete has to perform the following two functions:

1. The water enters into chemical action with cement and this action causes the setting and hardening of concrete.
2. The water lubricates the aggregates and it facilitates the passage of cement through voids of aggregates. This means that water makes the concrete workable.

NOTE Water-cement ratio and degree of compaction are the two major parameters which determine the strength of concrete. Higher the water-cement ratio, lower is the strength of concrete. Similarly, the strength is reduced with lower degree of compaction.

3.11 Workability of Concrete

- Workability is the amount of work to produce full compaction
- The important facts in connection with workability are:

  (i) If more water is added to attain the required degree of workmanship, it results into concrete of low strength and poor durability.

  (ii) If the strength of concrete is not to be affected, the degree of workability can be obtained:

  → By slightly changing the proportions of fine and coarse aggregates, in case the concrete mixture is too wet; and

  → By adding a small quantity of water cement paste in the proportion of original mix, in case the concrete mixture is too dry.

  (iii) The workability of concrete is also affected by the maximum size of the coarse aggregates to be used in the mixture.

  (iv) The workability of concrete is affected mainly by water content, water-cement ratio and aggregate-cement ratio.

3.12 Factors Affecting Workability

Following are the factors which affect the workability of concrete.

(a) Water content

(b) Mix proportions

(c) Size of aggregates

(d) Shape of aggregates

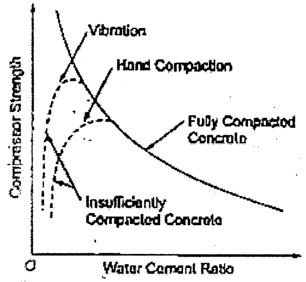
(e) Surface texture of aggregates

(f) Grading of aggregates

(g) Use of admixtures

3.12.1 Water Content/Water Cement Ratio

- Water content in a given volume of concrete will have significant influence on the workability.
- The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete which is one of the important factor affecting workability.
- According to Abram's law, the strength of workable concrete is only dependent on water-cement ratio.
- The volume of water in fresh concrete is related directly to the volume of empty pore space in hardened concrete. Similarly, the volume of cement in fresh concrete is related directly to the solid volume in hardened concrete. Water-cement ratio is therefore a measure of the void volume relative to the solid volume is hardened cement paste, and its strength goes up as the void volume goes down. So, the lower the water-cement ratio, the lower is the void volume-solid volume ratio and stronger the hardened concrete.
- In a hardened state concrete, strength is inversely proportional to the water/cement ratio as shown in the graph.
- The reason why the compressive strength of concrete does not actually follow a hyperbolic curve at lesser water-cement ratio is when water to cement ratio is low in a fresh mix, then less water is available for the hydration of cement. Hence, some amount of cement paste remains un-hydrated.



- The strength of concrete much dependent on the following four factors:
  1. Water to cement ratio
  2. Cement to aggregate ratio
  3. Maximum aggregate size
  4. Physical properties of aggregates

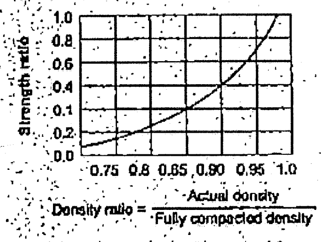
NOTE: The factors (2, 3 and 4) are of lesser importance while factor (1), is the major influencing factor

- The strength of concrete decreases with increase in percentage of air voids where air voids are formed by evaporation of water used in making concrete and by entrained air.

NOTE

- As a cement age increases it strength reduces since it get set partially by absorption of moisture and forms small lumps.
- When the uniaxial compressive load is applied where the line of action of load is perpendicular to the axis of the cube then load carrying capacity is assumed to be maximum.
- By increasing the cement to aggregate ratio the ultimate strength will increase upto some extent.
- The crushed aggregate gives maximum strength as it offers minimum voids in concrete.
- The rounded spherical or cubical shaped aggregate when compacted contains less voids than an irregular and flaky aggregate of the same nominal size and they give more strength. The strength order according to the type of aggregate as:

  1. Crushed aggregate > 2. Cubical aggregate > Rounded aggregate > Flaky/Irregular aggregate
- Inadequate compaction leading to air void contents of 5 per cent and of 10 per cent result in a loss of strength of 30 per cent and 55 per cent respectively.



Effect of Compaction on the Strength of Concrete

3.12.2 Mix Proportions/Aggregate Cement Ratio

- Aggregate/cement ratio is an important factor influencing workability.
- The higher the aggregate-cement ratio, leaner is the concrete.
- In lean concrete, less quantity of paste is available for providing lubrication per unit surface area of aggregate and hence the mobility of aggregate is restrained.
- In case of rich concrete with lower aggregate-cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

3.12.3 Size of Aggregate

- The bigger the size of the aggregate, lesser is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction.
- For a given quantity of water and paste, bigger size of aggregates will give higher workability.

3.12.4 Shape of Aggregate

- The shape of aggregates influences workability to a large extent.
- Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shape aggregates.
- Rounded aggregate will have less surface area and less voids than angular or flaky aggregate, not only that, being round in shape, the frictional resistance is also greatly reduced.
- Because of above reason, river sand and gravel provide greater workability to concrete than crushed aggregate and sand.

3.12.5 Surface Texture

- The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth, rounded aggregate of same volume.
- Smooth or glassy textured aggregate will give better workability.

3.12.6 Grading of Aggregates

- This is one of the factors which will have maximum influence on workability.
- A well graded aggregate is the one which has least amount of voids in a given volume
- Better the grading, lesser is the void content and higher is the workability.
- In order to measure the workability of concrete mixture, various tests are developed. Tests such as flow test, Vee-Bee test and compaction factor test are used in great extent in laboratory. Slump test, which is commonly used in the field, is briefly described below.

3.13 Tests for workability

3.13.1 Slump Test

- Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work.
- It is not a suitable method for very wet or very dry concrete and stiff mix.
- It does not measure all factors contributing to workability.
- The diameter of the rod is 16 mm and its length is 60 cm. The strokes to be given for ramming vary from 20 to 30.

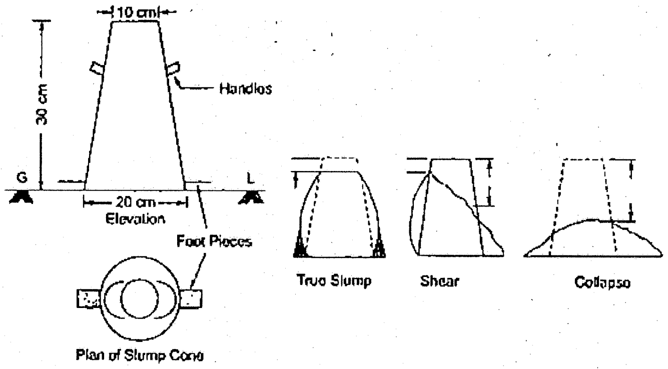


Fig. Slump Test

3.13.2 Procedure

- The mould is placed on a smooth, horizontal, rigid and non-absorbent surface.
- The mould is then filled in four layers, each layer approximately 1/4th of the height of the mould.
- Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section.
- The mould is removed from the concrete immediately by raising it slowly and carefully in vertical direction.
- This allows the concrete to subside.
- This subsidence is referred as SLUMP of concrete.
- The difference in levels between the height of the mould and that of the highest point of the subsided concrete is measured.
- The difference in height in mm is taken as slump of concrete.

Table: Recommended Slumps of Concrete

S.No.	Type of concrete	Slump
1.	Concrete for road construction	20 to 40 mm
2.	Concrete for tops of curbs, parapets, piers, slabs and walls that are horizontal	40 to 50 mm
3.	Concrete for canal linings	70 to 80 mm
4.	Concrete for arch and side walls of tunnels	90 to 100 mm
5.	Normal RCC work	80 to 150 mm
6.	Mass concrete	25 to 50 mm
7.	Concrete to be vibrated	10 to 25 mm

Table: Classification of Concrete Mixes

Slump	Nature of concrete mix
No slump	Stiff and extra stiff mix
From 10 mm to 30 mm	Poorly mobile mix
From 40 mm to 150 mm	Mobile mix
Over 150 mm	Cast mix

Advantages of Slump Test:

1. It grants the facility to easily detect the difference in water content of successive batches of concrete of the same identical mix.
2. The apparatus is cheap, potable and convenient to be used at site.

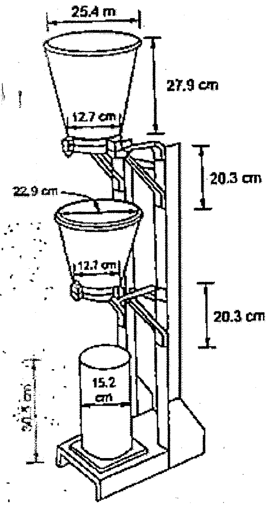
Limitations of Slump Test:

1. There is no direct relationship between the workability and the value of slump.
2. It is not suitable for a concrete in which maximum size of the aggregate exceeds 40 mm.
3. There are chances of many shapes of slump to occur and it is difficult to decide which-one is giving the correct value.
4. Slump occurs only in case of plastic mixes. It does not occur in case of dry mixes.

3.13.3 Compaction Factor Test

- In the compaction factor test, the degree of workability of concrete is measured in terms of internal energy required to compact the concrete thoroughly.
- A compaction factor of 0.95 represents flowing concrete having high workability; 0.92 plastic concrete having medium workability; 0.85 stiff plastic concrete having low workability and a compaction factor of 0.75 represents stiff concrete having very low workability.
- The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field.
- It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability and is normally used when concrete is to be compacted by vibration like, dry concrete which is insensitive to slump test.
- The test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height.

- The degree of compaction called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same fully compacted concrete.
- The sample of concrete to be tested is placed in the upper hopper up to the brim.
- The trap-door is opened so that the concrete falls into the lower hopper.
- Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.
- In the case of a dry mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion.
- The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus.
- The outside of the cylinder is wiped clean.
- The concrete is filled up exactly up to the top level of the cylinder.
- It is weighed to the nearest 10 gm.
- This weight is known weight of partially compacted concrete.
- The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep.
- The layers are heavily rammed or preferably vibrated so as to obtain full compaction.
- This weight is known as weight of fully compacted concrete



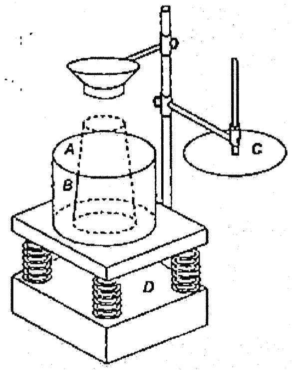
$$C.F. = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

Table Workability, Slump and Compacting Factor of Concretes with 20 mm or 40 mm Maximum Size of Aggregate

Degree of workability	Slump mm	Compacting factor		Use for which concrete is suitable
		Small apparatus	Large apparatus	
Very Low compacting factor is suitable	–	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand operated machines.
Low	25-75	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete maybe manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	50-100	0.92	0.935	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration
High	100-150	0.95	0.96	For sections with congested reinforcement. Not normally suitable for vibration For pumping and tremie placing.
Very High	–	–	–	Flow table test is more suitable.

3.13.4 Vee-Bee Test/Vee-Bee Consistometer Test

- This is carried out in such a manner that the specimen concrete in the test receives more or less same treatment in respect of the method of placing as it would in actual execution of the work. This test is preferred for finding workability of stiff concrete mix having very low workability.
- In this test, a Vee-Bee time of 3 to 5 seconds represents stiff plastic concrete having medium workability, 10 to 15 seconds represents stiff concrete of low workability and Vee-Bee time of 18 to 10 seconds represents very stiff concrete having very low workability.
- This is a good laboratory test to measure indirectly the workability of concrete
- This test consists of a vibrating table, a metal pot and a standard iron rod.
- Slump test as described earlier is performed, placing the slump concrete inside the sheet metal cylindrical pot of the consistometer.
- The glass disc attached to the arm is turned and placed on the top of the concrete in the pot
- The electrical vibrator is then switched on and simultaneously a stop watch started.
- The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.
- Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off.
- The time required for the shape of concrete to change from slump concrete shape to cylindrical shape in second is known as Vee Bee Degree.
- This method is very suitable for very dry concrete whose slump value can not be measured by slump test.



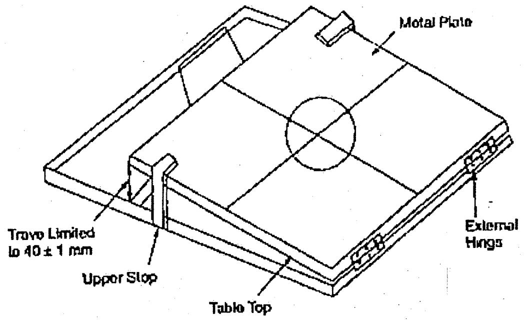
3.13.5 Flow Test

- This is a laboratory test which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation.
- In this test, a standard mass of concrete is subjected to jolting.
- The spread or the flow of the concrete is measured and this flow is related to workability.

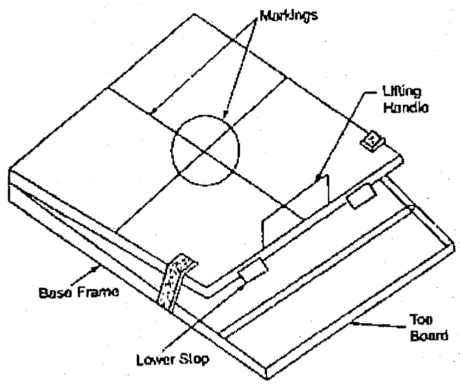
$$\text{Flow, percent} = \frac{\text{Spread diameter (in cm)} - 25}{25} \times 100$$

The value can range anything from 0-150%.

- It can be realized that the compacting factor test measures the inherent characteristics of the concrete which relates very close to the workability requirements of concrete and as such it is one of the good test to depict the workability of concrete.



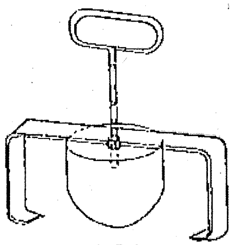
(a)



(b)

3.13.6 Kelly Ball Test

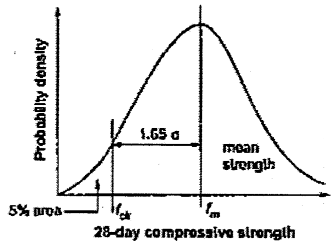
- This is a simple field test consisting of the measurement of the indentation made by 15 cm diameter metal hemisphere weighing 13.6 kg. When freely placed on fresh concrete. The test has been devised by Kelly and hence known as Kelly Ball Test.
- This has not been covered by Indian Standards Specification
- The advantages of this test is that it can be performed on the concrete placed in site and it is claimed that this test can be performed faster with a greater precision than slump test.
- It cannot be used when the concrete is placed in thin section.
- The minimum of concrete must be at least 20 cm and the minimum distance from the centre of the ball to nearest edge of the concrete 23 cm.



Kelly Ball

3.14 Strength Test on Concrete

- The strength of concrete is determine as compressive strength and tensile strength.
- The compressive strength of concrete is much greater than its tensile strength where the tensile strength is about 15% of its compressive strength.
- Quality or grade of concrete is designated in terms of a numbers, which denotes it characteristic compressive strength (of 150 mm cubes at 28 days), expressed in MPa (or equivalently N/mm^2).
- Number is usually preceded by the letter M, which refers to mix. For example M20 grade concrete denotes a concrete whose mix is so designed as to generate a characteristics strength of 20 MPa.
- But it is observed that tensile and bending strength of concrete are of the order of 10 and 15 per cent, respectively of the compressive strength and shear is approximately 20 per cent of the uniaxial compressive strength.
- Characteristic compressive strength is defined as strength of material below which not more than 5% of test results are expected to fall.
- It means that accordingly, the mean strength of the concrete f_m (as obtained from 28-day compression tests) has to be significantly greater than the characteristic strength f_{ck} that is specified by the designer.



28-day compressive strength
(Normal Distribution Curve)

3.15 Compressive Strength Test

- Cement, fine aggregate and coarse aggregate (up to 38 mm) to be used for making concrete are weighed in the ratio to be used in the field and area of hand mixing or by machine mixing.
- Now water is added and the entire batch mixed until the concrete appears to be homogeneous and has the desired consistency. Test specimens recommended are 150 × 150 / 150 mm cubes or cylinders of 150 mm diameter and 300 mm height.
- Mixed concrete is filled into the moulds in layers of 50 mm and each layer is tamped with bar 16 mm in diameter and 600 mm long 35 times or with a vibrator.
- Test specimens are stored at a temperature of 27 ± 3°C at 90% humidity for 24 ± 1/2 hour from the time of addition of water to the dry ingredients.
- After this time specimens are removed from the moulds and placed in water and kept there until taken out just before the test.
- Usually specimens are tested for 7 days or 28 days strength but IS code only suggest 28 days strength only.
- 7 days strength of concrete should be at least 2/3 of 28 day strength of concrete.
- Specimen is placed between the plates of the compression testing machine with the care that the axis of specimen is aligned with the centre of thrust of the spherically seated plate.
- Compression testing machine should be able to apply gradual load of 14 N/mm^2/minute. Till the specimen is crushed.
- Average of the three values is taken as the compressive strength of concrete, provided the individual variation is not more than ± 15 per cent of the average.

NOTE: IS code also recommends use of cubes of size 100 × 100 × 100 mm provided the aggregate size does not exceed 20 mm.

- The cube strength is ≈ 1.25 times cylinder strength.
- Cube compressive strength of concrete obtained from 15 cm cube is higher than 15 × 30 cm, cylinder compressive strength because contact area of a standard cube mould with the upper plane in the testing machine is more which results in more confinement. More confinements resist against specimen expansions resulting in more compressive strength.
- The compressive strength of concrete at 7 day should be about 2/3 of compressive strength of same concrete sample at 28 days.

3.16 Flexural Tensile Strength Test (Modulus of Rupture Test)

- Direct measurement of tensile strength of concrete is difficult.
- Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied to the concrete.
- Flexural tensile strength test is done to determine the tensile load at which concrete may crack.
- It is an indirect test for assessing the tensile strength of concrete.
- Same material is used as used for compressive strength test.
- Further concrete is filled in the mould of size 150 × 150 × 700 mm and tamped with the tamping bar weighing 2 kg, 400 mm long.
- Specimen is placed in the testing machine on two 38 mm diameter rollers with a c/c distance of 600 mm. Then load is applied through two similar rollers mounted at the third points of supporting span i.e.. spaced at 200 mm c/c.
- Load is applied without shock and increasing continuously at a rate of 0.7 N/mm²/minute until the specimen fails.

Modulus of rupture = $\frac{pl}{bd^2}$ $(a > 200\text{ mm})$, $\frac{3pa}{bd^2}$ $(200\text{ mm} > a > 170\text{ mm})$

a = distance between the line of fracture and the nearest support measured on the center line of the tensile side of the specimen (cm).

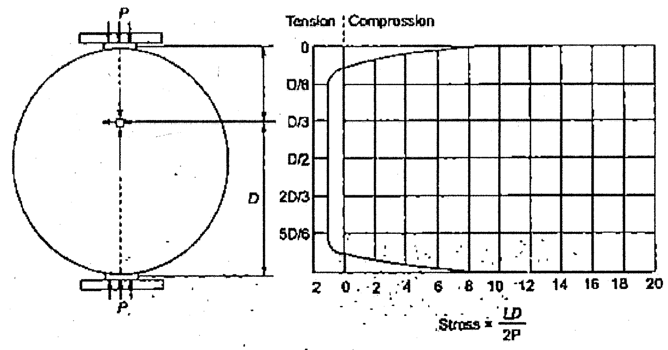
b and d is measured width and depth of specimen, respectively.

l = length of the span on which the specimen is supported (cm)

p = maximum load applied to the specimen.

3.17 Split Tensile Strength Test

- Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength is determined by indirect methods.
- It is the standard test to determine the tensile strength of concrete in indirect way in accordance with IS: 5816-1970.
- A standard test cylinder of concrete specimen of 300 mm × 150 mm diameter is placed horizontally between the loading surfaces of compression testing machine.
- The compression load is applied diametrically and uniformly along the length of cylinder until the failure of the cylinder along vertical diameter.
- On application of load, a uniform tensile stress acts over two-third of the loaded diameter
- The magnitude of the tensile stress is obtained by



$$\sigma = \frac{2P}{\pi DL}$$

where, P = Applied load

D = Diameter of the cylinder

L = Length of the cylinder

- The load is applied gradually and increased continuously until failure at a rate within the range of 1.2 MPa/min to 2.4 MPa/min.
- Between the loading platens and the specimen cylinder, packing strips of plywood are placed for uniform distribution of load and to avoid high compression stresses near the point of application.

Limitations of the Test:

- The test calculates the maximum tensile stress assuming line loads and a uniform distribution of tensile stresses, but concrete has a non-linear stress-strain distribution.
- The strength of specimen depends upon the diameter of the specimen and hence it is not necessarily a material property, but a reliable value that can be used for comparison and design.

3.18 Non Destructive Test

- Non-destructive testing (NDT) is a wide group of analysis techniques used to evaluate the properties of concrete without causing damage.
- So, instead of absolute values, an estimate of its strength, durability and elastic parameters are obtained.
- Though these tests are easy to perform but their analysis requires special knowledge.
- These test are conducted to keep a quality control of construction.

- Monitoring of strength development in relation to formwork removal, curing, prestressing load application or similar purposes.

1. Ultrasonic Pulse Velocity Test:
   - This test is based on the principle that velocity of sound in a solid material is a function of $\sqrt{E/\rho}$ where E is modulus of elasticity and ρ is density.
   - An ultrasonic pulse apparatus consists of a transmitter and a receiver which are held against two faces of concrete.
   - The apparatus generate pulse of ultrasonic frequency which are transmitted through concrete by the transmitter. On the other face, the receiver receives the pulse and the apparatus record them.
   - The velocity of the pulse is found which is correlated to the strength of the concrete.
   - Higher the velocity of pulse, greater the strength of concrete.
   - At present the ultrasonic pulse velocity method is the only one of dynamic test type that shows potential concrete strength in-situ.

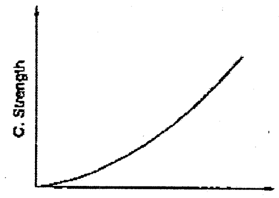
Quality of Concrete and Pulse Velocity	
General Condition	Pulse Velocity km/sec
Excellent concrete	4.5
Good concrete	3.5–4.5
Medium concrete	3–3.5
Doubtful concrete	below 3

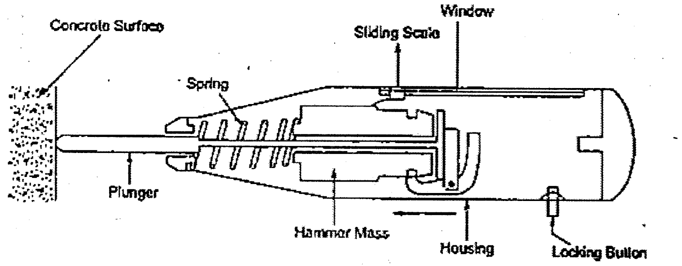
   Some major applications:
   - Estimation of Strength of Concrete
   - Establishing Homogeneity of Concrete
   - Determination of Dynamic Modulus of Elasticity

2. Rebound Hammer Test (Schmidt Hammer Test):
   - It is done to find out the compressive strength of concrete by using rebound hammer.
   - The principle of the test is that rebound of an elastic mass depends on the hardness of the surface against which it strikes.
   - When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of the rebound depends upon the surface hardness of the concrete.
   - The surface hardness and therefore the rebound are taken to be related to the compressive strength of the concrete.
   - The rebound value is read from a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer.

The procedure:

1. Apply light pressure on the plunger; it will release it from the locked position and allow it to extend to the ready position for the test.
2. Press the plunger against the surface of the concrete keeping the instrument perpendicular to the test surface. Apply a gradual increase in pressure until the hammer impacts.
3. The spring controlled mass when rebounds, it takes with it a rider which slides along a graduated scale. It can be held in position on the scale by depressing the locking button.
4. The test provides useful information for surface layer up to 30 mm depth and is suitable for concrete having strength of 20–60 MPa.
5. The concrete surface must be smooth and loose material should be ground off.





Some other commonly employed NDT methods:

1. Surface hardness tests
2. Dynamic or vibration tests
3. Radioactive and nuclear methods
4. Magnetic and electrical methods

3.19 Rheological Behaviour of Concrete

- Rheology is science of flow and deformation of matter and describes one interrelation between force deformation and time.
- Rheology of fresh concrete like workability includes the parameters of stability, mobility and compatibility.
- Mechanical behaviour of hardened cement paste, which exhibits both elastic and inelastic deformations can be expressed in rheological terms.
- The rheology deals with rate of shear and shear stress of concrete.

Factor Affecting Rheological Properties:

1. **Mix Proportions**
   - concrete having excess about of coarse aggregate will lack sufficient mortar to fill the void system, resulting in a loss of cohesion and mobility. Such a mix is termed harsh and requires a great amount of effort to place and compact.
   - Whereas an excessive amount f fine aggregate or entrained air in a concrete mixture will greatly increases the cohesion and render the concrete difficult to move.
2. **Consistency**
   - Consistency of concrete measured by the slump test is an indicator of the relative water content in the concrete mix.
   - An increase in the water content or slump above that required to achieve workable mix produces greater fluidity and decreased internal friction.
3. **Use of accelerating admixtures.**
   - High temperature; increase the rate of hardening which will decrease the mobility of concrete.
4. **Aggregate shape and texture**
5. **Aggregate grading**
   - Well graded aggregate gives good workability whereas Gap graded aggregate affects void and workability.
6. **Maximum size of aggregate**
   - Increase in the maximum size of aggregate will reduce the fine aggregate requirement to maintain a given workability and will thereby reduce the surface area to be wetted and hence the cement content necessary for a constant water-cement ratio.
7. **Admixtures**
   - Admixtures having significant effect on the rheology of concrete the plasticizers and super-plasticizers, air-entraining agents accelerators and regards.
   - Super-plasticizers and plasticizers prevent the formation of flocculated structure by changing the inter particle attracting repulsion.
   - Air-entraining agents introduce spherical air bubbles 10 to 25 mm to diameter by modifying the surface tension of the aqueous phase in the mix. Bubbles act like ball bearings to allow larger particles to flow past each other more easily thus decreasing plastic viscosity.

3.20 Types of Admixtures

- Admixtures are normally categorized according to their effect
  (a) Plasticizers (water-reducing agents)
  (b) Superplasticizers (high range water reducers
  (c) Air entrainers
  (d) Accelerators
  (e) Retarders
  (f) Others
- Many admixtures provide combinations of properties such as plasticizer/retarders or plasticizer/air entrainers. Each admixture type is discussed in the following sections.

3.20.1 Plasticizers (Water-reducers)

- Chemicals to improve plasticity of fresh concrete that is improving workability for a given w/c ratio and maintains workability with a reduced amount of water.
- Main types of plasticizers are lignosulphonic acids and their salts. (e.g. Ca, Na, NH, salts) hydroxylated carboxylic acids and their salts polyglycol esters and carbohydrates.
- The typical dosage of a plasticizer varies from 200 ml to 450 ml per 100 kg of cementitious material plasticizers are used in the amount of 0.1% to 0.4% by weight of cement.

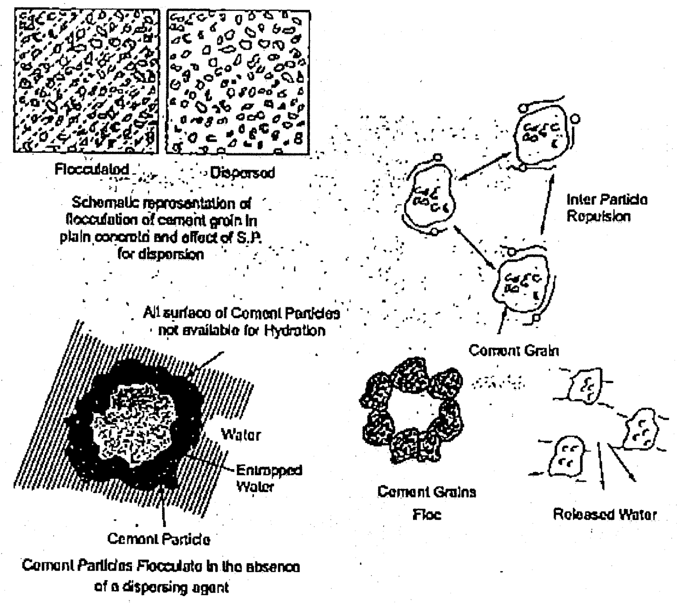


Fig. Effect of surface-active agents on deflocculating of cement grains

- When plasticizers are added they get adsorbed on the cement particles.
- The adsorption of charged polymer on the cement particles creates repulsive forces between particles. This repulsive force is called zeta potential which depends upon the quantity of plasticizer used.
- Hence structure of cement changes from flocculated to dispersed and thus water trapped inside the flocs gets released and fludify the mix.
- The adsorbed plasticizer on the surface of cement inhibits the surface hydration of cement as long as sufficient plasticizer are available.
- Plasticizer decreases as the polymers get entrapped in hydration products.

Uses:

- Plasticizers usually increase the slump of concrete with a given water content.
- Plasticizers can reduce the water requirement of a concrete mix for a given workability as a rule of thumb by about 10%.
- The addition of a plasticizer makes it possible to achieve a given strength with lower cement content.
- Plasticizers may improve pump ability.

3.20.2 Superplasticizers

- These admixtures are chemically distinct from normal plasticizers and although their action if basically the same, it is more marked.
- When they are used to produce flowing concrete a rapid loss of workability can be expected and therefore they should be added just prior to placing.
- Among the cement constituents C_3A exerts major influence on the properties of super-plasticizer.
- Finer the cement higher the super-plasticizer does.
- Examples are sulphonated melamine formaldehyde condensates, naphthalene sulphonates formaldehyde condensates, modified lignosulphonate (MLS) and mixture of saccharates and acid amines.
- Higher is the molecular mass higher is the efficiency of super-plasticizer.
- It is capable of reducing water requirement by 20 to 40%.

3.20.3 Air-entrainers

- An air-entraining agent introduces air in the form of minute bubbles distributed uniformly throughout the cement paste. The main types include salts of wood resin, animal or vegetable fats and oils and sulphonated hydrocarbons.
- Following are some of the examples of air entraining agents:
  1. Natural wood resins and their soaps, of which vinsol resin is the best.
  2. Animal or vegetable fats and oils such as tallow, olive oil and their fatty acids such as stearlic acids and oleic acids and their soaps.
  3. Wetting agents such as alkali salts or sulphated and sulphonated organic compounds.
- Air entrainment reduces the strength of concrete and overdosing can cause major loss of strength.
- 1% air may cause a strength loss of 5%.
- The use of ground blast furnace slag and fly ash tends to reduce the amount of air entrained.

Uses:

- Where improved resistance of hardened concrete to damage from freezing and thawing is required.
- For improved workability, especially in harsh or lean mixes.
- To reduce bleeding and segregation.

  The effect of air entrainment on the properties of concrete:

  (a) Reduces the tendencies of segregation.
  (b) Reduces the bleeding.
  (c) Decreases the permeability.
  (d) increases the resistance to chemical attack.
  (e) Permits reduction sand content.
  (f) Improves placeability and early finishing
  (g) Reduces the cement content cost, and heat of hydration.
  (h) Reduces the unit weight.
  (i) Permits reduction in water content
  (j) Reduces the alkali-aggregate reaction.
  (k) Reduces the modulus of elasticity.

3.20.4 Accelerators

- These admixtures (notably, clacium chloride) speed up the chemical reaction of the cement and water and so accelerate the rate of setting and/or early gain in strength of concrete.
- The less commonly used accelerators consist of NaCl, Na_2SO_3, NaOH, Na_2CO_3, K_2SO_4 and KOH.

Uses:

- Where rapid setting and high early strengths are required (e.g. in shaft sinking.)
- Where rapid turnover of moulds or formwork is required.
- Concreting takes place under very cold conditions.

NOTE

All chloride based accelerators promote corrosion of reinforcing steel and should not be used in
(i) reinforced concrete
(ii) water-retaining structures
(iii) Accelerators work more effectively at lower ambient temperatures.

3.20.5 Retarders

- These admixture slow the chemical reaction of the cement and water leading a longer setting times and slower initial strength gain.
- The most common retarder is calcium sulphate. Other examples includes hydroxylated carboxylic acids, lignins, sugar, cellulose products and some phosphates.

Uses:

- When placing concrete in hot weather, particularly when the concrete is pumped
- To prevent cold joints due to duration of placing.
- In concrete which has to be transported for a long time.

NOTE

- If a mix is overdosed beyond the limit recommended by the supplier, retardation can last for days.
- Retarders often increase plastic shrinkage and plastic settlement cracking.
- Delayed addition of retarders can result in extended retardation.

3.20.6 Water Proofer

- Cement mortar or concrete should be impervious to water under pressure and also should have sufficient resistance to absorption of water.

- Examples of water repellent materials such as soda and potash soaps are chemically active, whereas calcium soaps, resin, vegetable oils fats, waxes and coal tar residue.
- To stop bleeding, paraffin wax at about 0.2–0.75 percent by mass of cement or air entrainment is used. Air entrainment latter is more effective but requires high degree of control.

3.20.7 Pozzolanas

- These are siliceous materials which are themselves inactive but react in the presence of water with time to form compounds having cementitious properties.
- Pozzolanas react with free lime in cement and improve the durability of concrete, and reduces the rate of hardening of concrete, which is the principal objection to its use.
- Examples of pozzolana are lime, fly ash, burnt clay and blast furnace slag.

NOTE: The use of flyash as an admixture in concrete reduces the segregation are bleeding of concrete. It increases the workability of concrete.

- The main constituents of fly ash are:
  1. Silica 2. Aluminium oxide 3. Ferrous oxide
- Fly ash is a pozzolana. A pozzolana is a siliceous or aluminosiliceous material that, in finely divided form and in the presence of mixture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form additional calcium silicate hydrate and other cementitious compounds.

3.20.8 Estimating Yield of Concrete

- A rule-of-thumb as given below, may be used to find out the approximate yield of concrete from a given concrete mix.
- If the proportion of concrete is $a : b : c$, i.e., if a parts of cement, b parts of sand and c parts of coarse aggregates are mixed by volume, the resulting concrete will have a volume of 2/3 $(a + b + c)$.
- Let w, a, b and c be absolute volumes of water, cement, fine aggregate and coarse aggregate respectively, then, $w + a + b + c = 1$.

$$\text{Absolute volume} = \frac{\text{Weight of the materials}}{\text{Apparent sp. gr} \times \text{unit wt of water}}$$

- Bulking of sand should be taken into account when volumetric proportioning of the aggregates is adopted. Otherwise, less quantity of concrete per bag of cement will be produced, which naturally will increase the cost of concrete. Also, there will be less quantity of fine aggregate in the concrete mix which may make the concrete difficult to place.
- Let the bulking of sand be 25%. Then, for the concrete of proportion 1 : 2 : 4, the actual volume of sand to be used will be 1.25×2 instead of 2 per unit volume of cement. If this correction is not applied, the actual dry sand in the concrete will be $\frac{1}{1.25} \times 2 = 1.60$, instead of 2 per unit volume of cement. The proportion of concrete will then be 1 : 1.60 : 4. This indicates that less quantity of concrete will be produced and in most cases, there will not be enough quantity of fine aggregate to give a workable mix.

3.20.9 Water-proof Cement Concrete

Cement concrete to a certain extent may be made impermeable to water by using hydrophobic cement. Following are the three methods adopted for water-proofing of RCC flat roofs:

1. **Finishing:** For ordinary building of cheap construction, finishing of roof surface is done at the time of laying cement concrete. The finishing of flat roof is carried out in cement mortar of proportion 1 : 4, i.e., one part of cement to four parts of sand by volume.
2. **Bedding Concrete and Flooring:** In this method, the surface of RCC slab is kept rough and on this surface, a layer of concrete is laid. The concrete may be brickbats lime concrete (1 : 2 : 4) or brickbats cement concrete (1 : 8 : 14). The thickness of the concrete layer is about 10 cm.
3. **Mastic Asphalt and Jute Cloth:** In this method, a layer of hot mastic asphalt is laid on the roof surface. Jute cloth is spread over this layer.
4. **Use of water-proofing compounds:** Some of the water-proofing compound like Pudlo, Impermo, etc., are available in the market and when such a compound is added to the cement during construction, it prevents seepage, leakage and damp caused by the capillary absorption of the moisture in cement, mortar and concrete.

Advantages of using a good quality water-proofing compound are as follows:

(i) It corrects a badly proportioned concrete mixture.
(ii) It cures immature green concrete.
(iii) It makes good concrete free from the poor materials.
(iv) It permits less rigid supervision of the workmanship.

Coloured Concrete: It is used for the following purposes:

1. Manufacture of items for public welfare.
2. Ornamental finishes in buildings.
3. Preparing park lanes.
4. separating lines of traffic of road surfaces.
5. underground pedestrian crossings etc.

Lightweight Concrete: The bulk density of ordinary concrete is about 2300 kg/m^3. Concrete having bulk density between 500 to 1800 kg/m^3 is known as lightweight concrete and it is prepared from the following materials:

1. **Binding material :** Ordinary Portland cement and its varieties can be used as binding material.
2. **Aggregates :** For lightweight concrete, loose porous materials are used as aggregates.
3. **Steel :** Lightweight concrete is highly porous and hence, it leads to corrosion of reinforcement.

Advantages of Lightweight Concrete:

1. The local industrial waste, if found suitable for lightweight concrete, can be economically utilized.
2. The reduction in weight of concrete helps in easy removal, transport and erection of pre-cast products.
3. The use of lightweight concrete results in the reduction of cost to the extent of about 30 to 40% or so.
4. The lightweight concrete does not pose special problems with respect to freezing and thawing. It is due to the fact that the larger pores in aggregate are unlikely to become saturated, provided the cement paste is protected by air entrainment.

5. The lightweight concrete has comparatively less tendency to spall. Hence its fire resistance is more than that of ordinary concrete.
6. The lightweight concrete has generally a lower thermal expansion than ordinary concrete.

Do You Know? The only drawback of lightweight concrete is that the depth of carbonation i.e., the depth within which corrosion can occur under suitable conditions, is nearly twice than that of normal concrete. Hence special care will have to be taken to provide sufficient cover to the reinforcement of the lightweight structures to grant protection against corrosion.

No-fines Concrete: The no-fines concrete consists of cement, coarse aggregate and water. Thus the fine aggregate or sand is eliminated and such concrete has been adopted for cast-in-situ external load bearing walls of single and multi-storey houses, small retaining walls, damp-proofing a sub-base material etc.

Advantages of No-fines Concrete:

1. The drying shrinkage of no-fines concrete is relatively low.
2. No transmission of water by capillary action.
3. It is a type of lightweight concrete.
4. It possesses better insulating characteristics than conventional concrete.

Do you know? The unit weight of no-fines concrete is about two-thirds of the unit weight of conventional concrete. Hence the pressure on formwork is greatly reduced.

Aerated Concrete: It is manufactured from calcarious and silicious materials like cement, lime, pulverzed sand, flyash, etc. by entrapping air cells. These entrapped air cells make the material light, impervious and a good insulator of heat.

This concrete can be used for precast or cast in situ construction and can be produced in varying densities. This materials can be used for insulation, or for light load bearing roofs and floors. This can be reinforced if needed.

Heavy Weight Concrete: It can be produced by using specially heavy weight aggregates and compacting well by mechanical means. These concretes can be suitably used for gravity dams, retaining wall constructions or special atomic power plant vessels etc.

Pre-packed Concrete Construction: It is obtained by injecting cement sand mortar under pressure to fill voids of already packed and fully compacted coarse aggregates. This concrete is quite dense and has very small shrinkage.

General Precautions in Cement Concrete Construction: Following precautions should be observed:

1. Cement should be fresh and free from set cement particles.
2. Aggregates should be well graded and free from dirt, clay, silt and other deleterious materials.
3. Mixing water should be free from harmful chemicals and foreign materials.
4. The quantity of concrete prepared each time should be used and finished within 30 minutes or initial setting time of cement
5. Concrete should be prepared on a rigid, impervious and water tight platform without loosing any cement or water.
6. The quantity of cement, sand, coarse aggregate should be correctly measured either by volume or mass as desired in specifications of the mix proportion. Measurement by mass is more accurate and results in better quality construction.
8. Complete mixing of ingredients either by hand or by mixer should be ensured.
9. Care should be taken to avoid bleeding and segregation during transporting or placing concrete.
10. Form work or surface on which concrete is to be laid, should be cleaned and moistened with water before laying concrete.
11. The form work or other base on which concrete is to be laid should be checked for its rigidity, shape, size and other details and should be prepared well before concreting.
12. Shuttering and centering should be checked and ensured thoroughly before concreting operation.
13. Reinforcement and other components to be embedded in concrete should be thoroughly checked for their position, size, concrete cover and correct quantity before laying the concrete.
14. Laid concrete should be compacted thoroughly by manual tamping or mechanical vibration in layers of 150 to 450 mm. Care should be taken to avoid segregation and bleeding due to improper compaction.
15. During intermittent or concreting in different spells suitable construction joints should be formed to obtain a proper bond between the previously laid concrete and freshly laid concrete by using special techniques.
16. In long concrete structures, provide suitable expansion and contraction joints.
17. During extreme weather conditions, precautions for concreting should be taken by using special admixtures in suitable proportion and applying protective techniques of construction.
18. Concrete construction should be cured for sufficient period (14 to 28 days) as specified.
19. Shuttering and centering should be removed after a predetermined period and in a predetermined sequence.
20. Patch work or surface finish if any on the concrete surface should be done immediately on removal of shuttering and such a work should be properly cured for sufficient period (14 to 28 days).

3.20.10 Causes of Corrosion in Steel in Concrete

(i) Congested reinforcement in small concrete sections.
(ii) Excessive water-cement ratio.
(iii) Improper construction methods.
(iv) Inadequate design procedure.
(v) Insufficient cover to steel from exposed concrete surface.
(vi) Presence of moisture in concrete.
(vii) Presence of salts.

3.20.11 Effect of Corrosion

Important effect of corrosion is the formation of cracks and these cracks usually progress or advance most rapidly where shearing stresses are the greatest and where slipping occurs due to loss of bond.

3.21 Guniting

- The guniting is the most effective process of repairing concrete work which has been damaged due to inferior work or other reasons. It is also used for providing an impervious layer.

- Gunite is a mixture of cement and sand, the usual proportion being 1 : 3. A cement gun is used to deposit this mixture on the concrete surface under a pressure of about 2 to 3 kg/cm^2.
- The surface to be treated is cleaned and washed. The nozzle of gun is generally kept at a distance of about 75 cm to 85 cm from the surface to be treated and velocity of jet through nozzle varies from 120 to 160 m/sec.

Example 3.1 Design an M20 concrete mix as per IS 10262 : 2009 for the following conditions:

Type of exposure	:	Moderate
Slump	:	75–100 mm
Specific gravity of cement	:	3.15
Bulk density of cement	:	1450 kg/m^3
Quality control	:	Standard as specified in IS 456 : 2000
Sand		
Grading zone	:	III
Specific gravity	:	2.7
Bulk density	:	1695 kg/m^3
Free water present	:	1%
Coarse aggregate		
Size	:	20 mm graded and crushed
Specific gravity	:	2.9
Water absorption	:	0.35%
Bulk density	:	1590 kg/m^3

Solution:

Target mean strength

Given $f_{ck} = 20$ N/mm^2

Since quality control is as per the required standard and thus for M20 concrete, standard deviation (S) = 4 N/mm^2

Thus, target mean strength is :

$$f_{ck}' = f_{ck} + 1.65S$$
$$= 20 + 1.65 \times 4 = 26.6 \text{ N/mm}^2$$

Water cement ratio

For RCC work in moderate exposure condition, maximum water cement ratio = 0.50

Water content

For 20 mm maximum nominal size of aggregate with crushed particles for concrete with slump 25-50 mm, water content = 186 kg/m^3 of concrete.

But the slump required is 75–100 mm. Thus extra water content @3% per additional 25 mm slump = 2 x3% = 6%

Thus, water content = 1.06 × 186 = 197.16 kg/m^3 of concrete

Cement concrete required

For selected water cement ratio of 0.5 and water content of 197.16 kg, cement required

$$= \frac{197.16}{0.5} = 394.32 \text{ kg/m}^3 \text{ of concrete}$$

But minimum cement content required from durability consideration for moderate exposure condition

= 300 kg < 394.32 kg (OK)

The cement content of 394.32 kg/m^3 of concrete is OK.

Coarse and fine aggregate is total aggregates

Since fine aggregate is in Zone III where percentage of coarse aggregate for 20 mm maximum nominal size of aggregate is 0.64 at a water cement ratio of 0.5.

Now water cement ratio is 0.5 and thus no adjustment in the percentage of coarse aggregate is required.

Thus volume of coarse aggregate

$$V_{CA} = 0.64 \text{ times of volume of total aggregate}$$

So, volume of fine aggregate

$$V_{FA} = 1 - 0.64 = 0.36 \text{ times of volume of total aggregate}$$

Volume of total aggregate in concrete is given by

$$V_A = 1 - \left[\frac{C}{S_c} + \frac{W}{1}\right] \times \frac{1}{1000} = 1 - \left[\frac{394.32}{3.15} + \frac{197.16}{1}\right] \times \frac{1}{1000} = 0.678 \text{ m}^3$$

Therefore volume of coarse aggregate,

$$V_{CA} = 0.64 \times 0.678 = 0.434 \text{ m}^3$$

and volume of fine aggregate,

$$V_{FA} = 0.36 \times 0.678 = 0.244 \text{ m}^3$$

Thus, mass of coarse aggregate,

$$M_{CA} = 2.7 \times 0.244 \times 1000 = 658.8 \text{ kg per cubic meter of concrete}$$

Thus mix proportions are

Cement = 394.32 kg/m^3

Coarse aggregate = 1258.6 kg/m^3

Fine aggregate = 658.8 kg/m^3

Water = 197.16 kg/m^3

It is also given that coarse aggregate absorb water @ 0.35% and thus additional water is required and this addition

= 0.35 × 197.16 = 69 kg/m^3

Thus corrected water content = 197.16 − 1.97 + 69 = 264.19 kg/m^3

Corrected mass of coarse aggregate

= 1258.6 − 69 = 1189.6 kg/m^3

Corrected mass of fine aggregate

= 658.8 + 1.97 = 660.77 kg/m^3

Thus actual masses of materials required at site are:

Cement = 394.32 kg/m^3

Coarse aggregate = 1189.6 kg/m^3

Fine aggregate = 660.77 kg/m^3

Water = 264.19 kg/m^3

Given bulk densities of fine aggregate, coarse aggregate and cement as 1695 kg/m^3, 1590 kg/m^3 and 1450 kg/m^3 and thus mix proportion by volume is given by

$$\text{Cement: FA: CA} = \frac{394.32}{1450} : \frac{660.77}{1695} : \frac{1189.6}{1590}$$

$$= 0.272 : 0.39 : 0.748$$

$$= 1 : 1.43 : 2.75$$

$$\text{and water cement ratio} = \frac{264.19}{394.32} = 0.67$$

Example 3.2 Design an M40 concrete mix as per IS 10262 : 2009 using super plasticizers, fly ash and air-entrainment for the following data:

Type of exposure	:	Very severe
Slump	:	75–100 mm
Cement		
Cement	:	43 grade OPC
Specific gravity of cement	:	3.15
Bulk density of cement	:	1450 kg/m^3
Quality control	:	As per required standard
Air entrainment	:	3%
Super-plasticizer		
Specific gravity	:	1.1
Dosage	:	1.1%
Sand		
Fine aggregate (sand) grade	:	Grade II
Specific gravity	:	2.7
Coarse aggregate		
Size	:	20 mm crushed
Specific gravity	:	2.8
Water absorption	:	0.5%
Grading required	:	10 mm size 40% 20 mm size 60%

Solution:

$$f_{ck} = 40 \text{ N/mm}^2$$

For M40 concrete, standard deviation (s) = 5 N/mm^2

Target mean strength (f_{ck}') $= f_{ck} + 1.65\,S = 40 + 1.65 \times 5 = 48.25$ N/mm^2

Water-cement ratio

For very severe exposure condition, maximum water-cement ratio= 0.45

Water content

Assuming 20 mm nominal size of aggregate, water content = 186 kg per cubic meter of concrete provided slump is 25-50 mm

But slump given is 75-100 mm and thus increase water content @ 3% for every 25 mm increase in slump = 3 × 2 = 6%

Thus water content = 1.06 × 186 = 197.16 kg/m^3 of concrete

When super-plasticizers are used, water content can be decreased by up to 20%.

Thus water content = 0.8 × 197.16 = 187.73 kg per cubic meter of concrete

Cement content required

Water-cement ratio = 0.45

$$\text{Thus cement content} = \frac{187.73}{0.45} = 350.51 \text{ kg/m}^3 \text{ of concrete}$$

For very severe exposure condition, minimum cement content for durability consideration = 340 kg/m^3 < 350.51 kg/m^3 (OK)

$$\text{Thus water cement ratio} = \frac{157.73}{350.51} = 0.45$$

Coarse and fine aggregate in total aggregates

Since fine aggregate is in Zone II where percentage of coarse aggregate for 20 mm maximum nominal size of aggregate is 0.62 at a water cement ratio of 0.5. But actual water cement ratio is 0.45 which is 0.05 less than 0.5 and thus coarse aggregate percentage is to be increased by 0.01%.

Thus percentage of coarse aggregates = 0.62 + 0.01 = 0.72%

Thus volume of coarse aggregate

$$V_{CA} = 0.72 \text{ times of volume of total aggregate}$$

So, volume of fine aggregate

$$V_{FA} = 1 - 0.72 = 0.28 \text{ times of volume of total aggregate}$$

Dosage of super plasticizer = 1.1%

Super plasticizer required = 1.1% of cement required = 0.011 × 350.51 = 3.86 kg/m^3

Air entrainment (v) = 3% = 0.03

Volume of total aggregate in concrete is given by

$$V_A = 1 - \left[\frac{C}{S_c} + \frac{W}{1} + \frac{F}{S_f} + \frac{F}{S_p}\right] \times \frac{1}{1000} - v$$

$$= 1 - \left[\frac{350.51}{3.15} + \frac{157.73}{1} + 0 + \frac{3.86}{1.1}\right] \times \frac{1}{1000} - 0.03 = 0.757 \text{ m}^3$$

Therefore volume of coarse aggregate,

$$V_{CA} = 0.72 \times 0.757 = 0.545 \text{ m}^3$$

and volume of fine aggregate

$$V_{FA} = 0.28 \times 0.757 = 0.212 \text{ m}^3$$

Thus, mass of coarse aggregate,

$$M_{CA} = 2.8 \times 0.545 \times 1000 = 1526 \text{ kg/m}^3 \text{ of concrete}$$

Mass of fine aggregate, $M_{FA} = 2.7 \times 0.212 \times 1000 = 572.4$ kg/m^3 of concrete

Thus mix properties are:

Cement = 350.51 kg/m³
Coarse aggregate = 1526 kg/m³
Fine aggregate = 572.4 kg/m³
Water = 157.73 kg/m³
Super plasticizer = 3.86 kg/m³
Air entrainment = 3%
Water-cement ratio = 0.45

Cement : Sand : Coarse aggregate

= 350.51 : 572.4 : 1526 = 1 : 1.63 : 4.35

Example 3.3 Calculate the quantities of cement, sand and coarse aggregate required to produce one cubic meter of concrete for mix properties of 1 : 10 : 2.80 (by volume) with water-cement ratio of 0.18 (by mass) Bulk densities of cement, sand and coarse aggregates are 11.7, 16.66 and 18.68 kN/m³ respectively. Percentage of entrained air is 2.0. Specific gravities of cement, sand and coarse aggregate are 3.15, 2.6 and 2.5 respectively.

Solution:

Cement : F.A. : CA

$$x\text{m}^3 : 1.4 \times \text{m}^3 : 2.85\,x\text{m}^3\text{s} \quad \frac{\text{Weight of water}}{\text{Weight of cement}} = 0.48$$

$$\frac{\text{Weight}}{\text{Volume}} = \text{Absolute density } (e_s) = \frac{W_S}{V_S}$$

$$e_{\text{bulk cement}} = 14.7 \text{ kN/m}^3$$
$$e_{\text{bulk FA}} = 16.66 \text{ kN/m}^3$$
$$e_{\text{bulk CA}} = 15.68 \text{ kN/m}^3$$

$$\frac{\text{Weight}}{\text{Volume}} = \frac{\text{Weight of solid}}{V_S + V_{air}} = \text{Bulk density}$$

$\therefore$ Cement : FA : CA – (14.7 × kN) : (1.4 × 16.66 × kN) : (15.68 × 2.8x)

Weight of water = 0.48 × weight of cement = 0.48 × 14.7 × kN

$$\text{Volume of water} = \frac{0.48 \times 14.7x}{\gamma_w}\text{m}^3 \quad \text{Vol. of air} = 0.02 \text{ m}^3$$

$$\therefore \frac{14.7x}{3.15\gamma_w} + \frac{1.4 \times 16.66x}{2.6\gamma_w} + \frac{15.68 \times 2.8x}{2.5\gamma_w} + \frac{0.48 \times 14.7x}{\gamma_w} + 0.02 \text{ m}^3$$

$$x = 0.257 \text{ m}^3$$

Now, Weight of cement = 14.7x = 3.777 kN = 377.7 kg [1 kN = (100 kg)]

Weight of FA = 1.4 × 16.66x = 5.994 kN = 59.4 kg

Weight of CA = 15.68 × 2.8x = 11.283 kN = 1128.3 kg

Weight of water = 0.48 × 143.7x = 0.48 × 377.7 = 181.296 kg

Example 3.4 Estimate the quantities of cement, fine aggregate and coarse aggregate per cubic metre of concrete if the void ratio in cement is 62% fine aggregate is 11% and coarse aggregate is 45%. The material properties are as follows:

Mix : 1 : 2 : 4 with a w/c of 0.55, one bag of cement contains 50 kg of cement and its density is 14.10 kg/m³. The density of fine aggregate is 1700 kg/m³ and coarse aggregate is 1600 kg/m³ respectively. One bag of cement is equal to 34.7 litres.

Solution:

When the mix proportion is given line 1 : 2 : 4 and it is not mentioned whether it is by volume or by weight, we should always take it as by weight like 1 kg cement : 2 kg fine aggregate : 4 kg coarse aggregate

Also bulk density or simply density of cement means

$$\text{Bulk density or density of cement} = \frac{\text{Mass of cement}}{\text{Vol. of cement}}$$

on the other hand, absolute density or mass density means,

$$\text{Absolute density or mass density of cement} = \frac{\text{Mass of cement}}{\text{Vol. of cement solid}}$$

$$\text{Mass density} = \frac{W_S}{V_S}$$

$$\text{Bulk density} = \frac{W_S}{V} = \frac{W_S}{V_S \cdot V_V} = \frac{W_S / V_S}{1 + \frac{V_V}{V_S}}$$

$$\text{Bulk density} = \frac{\text{Mass density}}{1 + e}$$

where, $e_{cement} = 0.62$, $e_{fine\ aggregate} = 0.41$, $e_{course\ aggregate}$

Bulk density of cement = 1440 kg/m³

Bulk density of fine aggregate = 1700 kg/m³

Bulk of coarse aggregate = 1600 kg/m3

Mass density of cement, ρ = (Bulk density of cement) × (1 + e_c)

ρ = 1440 × 1.62 = 2332.8 kg/m³

ρ = 1700 × 1.40 = 2391 kg/m³

ρ = 1600 × 1.45 = 2320 kg/m³

Let the volume of air in 1 m³ of concrete = 0.02 m³

Sum of vol. of all ingredients = Vol. of concrete

Let the mass of cement in 1 m³ of concrete be x kg

x kg of cement is to be mixed with $2x$ kg fine aggregate and $4x$ kg coarse aggregate and as W/C ratio is 0.55, wt. of water is 0.55 x.

$$\frac{x}{2332.8} + \frac{2x}{2397} + \frac{4x}{2320} + \frac{0.55}{1000} + 0.02 = 1$$

$$x = 27.06 \text{ kg}$$

Wt. of cement for 1 m³ concrete = 277.06 kg

Wt. of F.A. for 1 m³ concrete = 554.12 kg

Wt. of C.A. for 1 m³ concrete = 1108.24 kg

Wt. of water for 1 m³ concrete = 152.383 kg

Objective Brain Teasers

Q.1 The aggregate crushing value of coarse aggregates which is used for making concrete, which in turn is used for purposes other than wearing surfaces, should not exceed
(a) 30% (b) 40%
(c) 45% (d) 50%

Q.2 For a given environment, the most significant factor that influences the total shrinkage of concrete is
(a) cement content of mix
(b) total amount of water added at the time of mixing
(c) size of the member concreted
(d) maximum size of the coarse aggregate used

Q.3 Putty is made up of
(a) white lead and turpentine
(b) powered chalk and raw linseed oil
(c) red lead and linseed oil
(d) zinc oxide and boiled linseed oil

Q.4 The compacting factor test of cement concrete determines its
(a) strength
(b) porosity
(c) degree of compaction under loads
(d) workability

Q.5 The limit of proportionality is applicable more in the case of
(a) concrete (b) wood
(c) cast iron (d) mild steel

Q.6 If p is the standard consistency of cement, the amount of water used in conducting the initial setting time test on cement is
(a) 0.65 p (b) 0.85 p
(c) 0.6 p (d) 0.8 p

Q.7 If in a concrete mix the fineness modulus of coarse aggregate is 7 6, the fineness modulus of fine aggregate is 2.8 and the economical value of the fineness modulus of combined aggregate is 6.4, then the proportion of fine aggregate is
(a) 25% (b) 33.33%
(c) 50% (d) 66.67%

Q.8 Tensile strength of concrete is measured by
(a) direct tension test in the universal testing machine
(b) applying compressive load along the diameter of the cylinder
(c) applying third point loading on a prism
(d) applying tensile load along the diameter of the cylinder

Q.9 A splitting tensile test is preformed on a cylinder of diameter 'D' and length 'L'. If the ultimate load is 'P', then the splitting tensile strength of concrete is given by
(a) $\frac{P}{\pi DL}$ (b) $\frac{2P}{\pi DL}$
(c) $\frac{4PL}{\pi D^2}$ (d) $\frac{2PD}{\pi L^3}$

Q.10 Consider the following statements:
Addition of surfactants in the concrete mix results in
1. Increase in the water cement ratio
2. decrease in the water cement ratio
3. increase in the strength of concrete
4. decrease in the curing duration
5. increase in the density of concrete

Of these statements:
(a) 1, 3 and 4 (b) 2, 3 and 5
(c) 3, 4 and 5 (d) 1, 4 and 5

Q.11 To make one cubic meter of 1 : 2 : 4 by volume concrete, the volume of coarse aggregates required is
(a) 0.95 m^3 (b) 0.85 m^3
(c) 0.75 m^3 (d) 0.65 m^3

Q.12 Consider the following statements.
The effect of air entrainment in concrete is to
1. increase resistance to freezing and thawing
2. improve workability
3. decrease strength

Which of these statements are correct?
(a) 2 and 3 (b) 1 and 3
(c) 1 alone (d) 1, 2 and 3

Q.13 Consider the following strength of concrete:
1. Cube strength
2. Cylinder strength
3. Split-tensile strength
4. Modulus of rupture

The correct sequence in increasing order of these strength is
(a) 3, 4, 2, 1 (b) 3, 4, 1, 2
(c) 4, 3, 2, 1 (d) 4, 3, 1, 2

Answers

1. (c)	2. (b)	3. (b)	4. (d)	5. (d)
6. (b)	7. (b)	8. (c)	9. (b)	10. (b)
11. (b)	12. (d)	13. (a)		

■■■■