Chapter 1

Concrete and Its Constituents

CHAPTER HIGHLIGHTS

- *Cement*
- *Aggregates*
- *Admixtures*
- *Concrete*

Cement

Chemical Composition

Ordinary cement contains two basic ingredients, namely, argillaceous and calcareous. In argillaceous materials, clay predominates and in calcareous calcium carbonate predominates.

Broadly, the raw materials used for manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another at high temperature and form more complex compounds. The relative proportions of these oxide compounds are responsible for influencing the various properties of cement, in addition to rate of cooling and fineness of grinding.

Approximate oxide composition ranges for ordinary portland cement (OPC) are:

Ingredient	Chemical Formula	Range (%)
Lime	CaO	62–67
Silica	SiO_2	17–25
Alumina	Al_2O_3	3–8
Calcium Sulphate	$CaSO_4$	3–4
Iron oxide	Fe_2O_3	3–4
Magnesia	MgO	1–3
Sulphur	S	1–3
Alkalies	–	0.2–1

Functions of Cement Ingredients

1. **Lime (CaO):** Excess lime makes the cement unsound and causes the cement to expand and disintegrate. Deficiency in lime makes loss of strength and makes cement to set quickly.
2. **Silica (SiO_2):** SiO_2 imparts the strength to cement by forming the di-calcium and tri-calcium silicates. Excess silica makes the strength of cement increases, but prolongs the setting time.
3. **Alumina (Al_2O_3):** Al_2O_3 imparts quick setting property to the cement. It acts as a flux and lowers the clinkering temperature. Excess alumina makes cement weaker.
4. **Calcium Sulphate ($CaSO_4$):** It is in the form of gypsum and increases the initial setting time of cement.
5. **Iron Oxide (Fe_2O_3):** Fe_2O_3 imparts colour, hardness and strength to cement.
6. **Magnesia (MgO):** MgO imparts hardness and colour, if present in small amount. Excess MgO makes cement unsound.
7. **Sulphur (S):** It is useful in making sound cement.
8. **Alkalis:** Most of the alkalis present in raw materials are carried away by the flue gases during heating process. Presence of alkalis causes problems such as alkali-aggregate reaction, efflorescence and staining, etc.

The above mentioned constituents in chemical reactions form the following compounds, called 'bogue's compounds'.

Tri-calcium silicate (Alite)	C_3S	45%
Di-calcium silicate (Belite)	C_2S	25%
Tri-calcium Aluminate (celite)	C_3A	11%
Tetra-calcium Alumino Ferrite (Felite)	C_4AF	9%

The functions of each of these compounds are as follows:

1. C_3S
   - Hydrates quickly and contributes more to the early strength.
   - High heat of hydration.
2. C_2S
   - Strengthen the concrete from 7days – 1 year.
   - Less heat of hydration.
   - Initial setting of cement.
3. C_3A
   - Small contribution to the strength within first 24 hours.
   - Very high heat of hydration.
4. C_4AF
   - Comparatively inactive.

Types of Cements

1. **Ordinary portland cement (OPC):**
   - OPC is used in general concrete construction where there is no exposure to sulphates in soil or in groundwater.
   - Initial and final setting times are 30 minutes and 10 hours.

Different Grades of Ordinary Portland Cement (OPC)

Grade of Cement	Details
33 grade ordinary portland cement (IS:269-1998)	• The compressive strength after 28 days is 33 N/mm^2. • Used for general construction works in normal environmental conditions. • Cannot be used where higher grade concrete above M20 is required.
43 grade ordinary portland cement (IS:8112-2000)	• Minimum 28 days compressive strength 43 N/mm^2. • Used for construction of residential, commercial and industrial building, roads, bridges, flyovers, irrigation projects and other general civil construction works. • Suitable for all types of applications RCC, plastering, masonry, etc.
53 grade ordinary portland cement (IS:12269-1999)	• Minimum 28 days compressive strength 53 N/mm^2. • Gives 10–15% saving in cement consumption and 5–8% saving in steel consumption provided higher grades of concrete, say M30 and above. • Useful for high-rise buildings, bridges, flyover, chimneys and pre-stressed structures where high-grade concrete is required. • Gives better durability characteristics to concrete.

2. **Rapid hardening cement:**
   - Contains high percentage of C_3S to the extent about 56%.
   - 3 days strength is equivalent to 7 days strength of OPC.
   - Initial and final setting times are as same as OPC.

   Advantages:
   - Sets rapidly and requires a short period of curing.
   - Early removal of formwork.
3. **Extra rapid hardening cement:**
   - Imparts strength about 25% higher than that of rapid hardening cement.
   - It is obtained by inter-grinding calcium chloride ($CaCl_2$) with rapid hardening of portland cement.
4. **Low heat cement:**
   - Contains lower % of C_3A of about 5% and higher % of C_2S about 46%.
   - Initial setting time is about an hour and final setting time is about 10 hours.
   - Mainly used for mass concrete works.
5. **Hydrophobic cement:**
   - Contains admixtures which decrease the wetting ability of cement grains.
   - Frost resistance and water resistance of concrete can be increased by using this type of cement.
   - Examples for hydrophobic admixtures includes oleic acid, oxidized petroleum, naphthalene, soap, etc.
6. **Quick setting cement:**
   - Produced by adding small percentage of aluminium sulphate and by finely grinding the cement.
   - Setting action starts within 5 minutes after addition of water and within 30 minutes it hardens.
   - Used to lay concrete under water.
7. **Expanding cement:**
   - Produced by adding an expanding medium like sulpho-aluminate and a stabilizing agent to OPC.
   - Used for repairing damaged concrete surfaces and for construction of water retaining structures.
8. **High alumina cement:**
   - Produced by grinding clinkers formed by calcined bauxite and lime.
   - Initial setting time is more than $3\frac{1}{2}$ hours and final setting time is about 5 hours.
   - Acid resistant, but high heat of hydration.
9. **Pozzolana cement:**
   - Pozzolana is a silicacious material which has no cementitious properties when it is used alone, but in the presence of cement it posses cementitious properties.
   - Pozzolana materials should be between 10–30%.
   - Fly ash, blast furanace slag, silica fume are examples for artificial pozzolans and burnt clay, pumicite are examples for natural pozzolana materials.

- Used to prepare mass concrete of lean mix and for marine works sewage works and for laying concrete under water.

10. **White cement and coloured cement:**
    - Used for finishing, plastering and architectural, and ornamental works.
    - Colouring agents, such as iron oxide, cobalt, manganese dioxide, etc., are added to white cement to obtain red and yellow, blue and black colour cements.

Tests on Cement

Field Tests

Carried out to roughly ascertain the quality of cement.

1. **Colour:**
    - Should be uniform and in grey colour with light greenish shade.
    - Gives an indication of excess lime or clay and the degree of burning.
2. **Physical properties:**
    - Should feel smooth when rubbed between fingers.
    - It should sink, but not float when small quantity of cement thrown in a bucket.
    - Should feel cool and not warm when hand is inserted in a bag/heap of cement.
3. **Presence of lumps:**
    - Should be free from any hard lumps.

Laboratory Tests

1. **Fineness:**
    - Carried out to check proper grinding of cement.
    - Determined either by sieve test or by permeability apparatus test.
    - In permeability test, 'specific surface area' is calculated as a measure of frequency of the average size of particles, expressed in cm^2/g.
    - It should not be less than 2250 cm^2/g for OPC, 3250 cm^2/gm for rapid hardening and 3200 cm^2/gm for low heat cements.
2. **Consistency:**
    - To determine the % of water required for making workable cement paste.
    - Apparatus used: Vicat's apparatus with Vicat plunger of 1 cm diameter.
    - As per Vicat's test, percentage of water added to cement at which the needle penetration is in between 5–7 mm (from the bottom of the mould) is called 'consistency'.
    - For OPC, consistency is around 30%.
3. **Setting times:**

    Initial setting time: Determined by Vicat's apparatus using Vicat's needle of 1 mm squared needle.

    - Water added to cement is about 0.85 times the water required for standard consistency. Weight of the cement taken is 300 g to carry out this test.
    - Period elapsing between the time when water is added to the cement and the time at which the needle fails to pierce the test block by 5 ± 0.5 mm is taken as the initial setting time.
    - For OPC, it should not be less than 30 minutes. For low heat cements, it should not be less than 60 minutes.

    Final setting time: Determined by Vicat's apparatus using Vicat's needle with annual collar of 5 mm diameter.

    - Time lapsed since addition of water to time at which needle with annual collar can only make a mark on hard concrete surface, but not piercing is taken as final setting time.
    - It should not be more than 10 hours for OPC.
4. **Soundness:**
    - Soundness refer to the ability of cement to maintain constant volume.
    - Carried out to detect the presence of un-combined lime in cement.
    - Determined by Le Chatelier apparatus, or Autoclave test.
    - Le Chatelier's method measures expansion due to lime, and Autoclave method measures expansion due to magnesia.
    - Expansion more than 10 mm indicates unsoundness of cement.
5. **Heat of hydration:**
    - Hydration is the process of adding water to cement.
    - Determined by adiabatic calorimeter test or vacuum flask test.
    - For OPC, heat of hydration at 7 days should not be more than 65 cal/g, and at 28 days should not more than 75 cal/g.
6. **Specific gravity:**
    - Determined through test conducted—using kerosene and specific gravity bottle at 27° temperature.
    - Specific gravity for OPC is about 3.1.

Some Important Specifications—OPC	
Fineness (cm^2/gm)	2250 minimum
Setting times	
Initial	30 hours duration
Final	10 hours maximum
Specific gravity	3.1
Compressive strength (kg/cm^2)	
3 days	230 minimum
7 days	330 minimum
28 days	430 minimum

Aggregates

- Aggregates are the inert or chemically inactive materials, which are considered to be as important constituents in concrete.
- The aggregates may be classified as natural and artificial aggregates based on source of the aggregates.
- Examples for natural aggregates include sand, gravel, crushed-rock such as granite, quartz, basalt, sand stone, etc. Similarly, examples for artificial aggregates include broken-brick, slag, bloated clay, sintered fly ash, etc.

Properties of Aggregates

1. **Size:** On the basis of size, these are classified into two categories. These are:
   (a) Fine aggregates
   (b) Coarse aggregates
   The size of aggregate bigger than 4.75 mm is considered as coarse aggregate. The size of aggregate whose size is 4.75 mm and less is considered as fine aggregate. The maximum size of aggregate should be as large as possible within the specified limits, but in any case not greater than $\frac{1}{4}$ of the minimum thickness of the member.
2. **Shape:** Since shape of aggregate affects the workability of concrete, it is considered to be an important characteristic of aggregate.
   - Rounded aggregates are preferable to angular aggregates for a given water cement ratio.
   - In contrast, angular aggregates exhibits better interlocking effect, higher bond strength than rounded aggregates which makes this suitable for roads and pavements construction.
3. **Texture:** Rough textured aggregate develops higher bond strength in tension than smooth textured aggregate.

Tests on Aggregates

Aggregate Crushing Value

- Aggregate crushing value gives a relative measure of 'resistance of an aggregate to crushing under gradually applied compressive load.'
- The crushing value of aggregate is restricted to 30% for concrete used for roads and pavements and 45% may be permitted for other structures.

Aggregate Impact Value

- Measures toughness of aggregate.
- Toughness is usually considered as the 'resistance of the material to failure by impact.'
- Aggregate impact value shall not exceed 45% by weight for aggregate used for concrete other than wearing surface and 30% by weight for concrete for wearing surfaces, such as runways, roads and pavements.

Aggregate Abrasion Test

- Measures hardness or 'resistance against wear', which is important for aggregates to be used for road and pavement construction.
- Common tests to measure abrasion resistance are:
  (a) Deval attrition test
  (b) Dorry abrasion test
  (c) Los Angels test

Bulking of Aggregates

- Free moisture content in fine aggregate results in bulking of volume.
- Free moisture forms a film around each particle, and this film exerts surface tension which causes the bulking of sand.

Flakiness Index

- It is the % by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension.
- This test is not applicable to sizes smaller than 6.3 mm.

Elongation Index

- It is the % by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension.
- This test is also not applicable to sizes smaller than 6.3 mm.

Specific Gravity and Water Absorption

- Test methods for determining these properties are based on 'archimedes principle'.
- Specific gravity $= \frac{C}{B-A}$
- Apparent specific gravity $= \frac{C}{C-A}$
- Water absorption $= \frac{100(B-C)}{C}$

Where
A = Weight (in g) of saturated aggregate in water
B = Weight (in g) of saturated surface dry aggregate in air
C = Weight (in g) of oven-dried aggregate in air

- Specific gravity for aggregates commonly used in construction varies between 2.5–3.
- Water absorption is generally regarded as measure of 'porosity' and it varies from 0.1–2 per cent.

Stripping Value Test

- Also known as 'bitumen affinity' test and is carried out to know the behaviour of aggregates towards bitumen.

- Aggregates can be classified into 2 categories:
  (a) Hydrophilic
  (b) Hydrophobic
- Hydrophilic are water liking and they lose their bituminous coating in presence of water. On the other hand, hydrophobic retains bituminous coating even in presence of water.

Angularity Number

- It indicates the amount by which the percentage voids exceeds 33% after being compacted in prescribed manner.
- Angularity number = 67% solid volume
- The angularity number is expressed to the nearest whole number, and it ranges for aggregates used in construction is from 0 to 11.

Admixtures

Admixture is defined as a material other than cement, water and aggregates, that is used an ingredient of concrete and is added to batch immediately before or during mixing.

Types of Admixtures

Mineral Admixtures

1. Fly ash
2. Silica fume
3. Ground granulated blast furnace slag (GGBS)
4. Stone powder, etc.

Chemical Admixtures

1. **Accelerators:**
   - Increases the rate of strength development or reduces the setting time.
   - Calcium chloride ($CaCl_2$) is widely used accelerator.
   - Other examples include tri-ethenoalamine, fluosilicates, etc.
2. **Retarders:**
   - Delays the setting time of cement paste.
     Examples: Gypsum (calcium sulphate), mucic acid, calcium acetate, sugar, etc.
3. **Plasticizers (water reducers):**
   - Increases the workability of concrete without altering the water/cement ratio.
     Examples: Ligno sulphuric acids in form of calcium or sodium salts, oleate, etc.
4. **Super plasticizers (high range water reducers):**
   - Imparts very high workability with large decrease in water content (at least 20%) for a given workability.
     Examples: Hydroxylated carboxylic acids, formaldehyde derivates, such as melamine formaldehyde, naphalene sulphonate formaldehyde, etc.

Uses of Admixtures

Admixtures are used to:

1. Accelerate or retard setting times.
2. Decrease heat of evolution, rate of bleeding, segregation.
3. Increase the rate of hydration and strength development.
4. Increase water tightness and reduce capillary flow, etc.

Concrete

Fresh concrete: Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape.

Workability

Workability is defined as the property of concrete which determines the amount of useful internal work necessary to produce full compaction.

In another words, it is defined as the 'ease with which concrete can fully compacted having regard to the mode of compaction and place of deposition.

The following factors affect the workability of concrete.

Water Content

- Higher the water content, higher will be the fluidity of concrete.
- It is important to maintain the water and cement ratio constant while adding water to the concrete, for the purpose of achieving high workability.

NOTE

Water and cement ratio, more than 0.38, will results in capillary cavities. A ratio which is less than this will result in incomplete hydration.

Mix Proportions

- Higher the aggregate and cement ratio, leaner the concrete.
- In lean concrete, less quantity of paste is available for lubrication per unit surface area of aggregate; hence mobility of aggregate is restrained.
- On the other hand, lesser the aggregate and cement ratio, higher the work-ability.

Size and Shape of Aggregate

- Bigger the size of aggregates, higher the workability.
- Angular, elongated, or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cube-shaped aggregates.

Surface Texture

- Smooth or glassy-textured aggregate gives better workability than the aggregates of rough texture.

Grading of Aggregates

- Better the grading, lesser the void content, and higher the workability.

Use of Admixtures

- Plasticizers and super-plasticizers greatly improve the workability of the concrete.
- Fine glassy puzzolanic materials, air-entraining agents offer better lubricating effect, hence better workability.

Tests on Workability

Slump Test Appartus

1. Metallic mould in the form of frustum of cone having internal dimensions as:
   - Bottom diameter: 20 cm
   - Top diameter: 10 cm
   - Height: 30 cm
2. Steel tamping rod of 16 mm diameter and 0.6 m long with a bullet end.
   - Mould/slump cone is filled with the fresh concrete in four layers, and each layer is tamped for 25 times by a standard tamping rod. The subsidence of concrete under gravity in 'mm' is called 'slump'.
   - Recommended slumps for various concrete placing conditions (in mm) are:

Placing Conditions	Slump (in mm)
Mass concrete: Llightly reinforced sections in slabs, beams, floors, columns, strip footings.	25–75
Heavily reinforced section in slabs, beams, columns.	50–100
Slipform work, pumped concrete	75–100
Trench fill	100–150

Compaction Factor Test

- This 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 the density of same fully-compacted concrete.

Compacting factor (CF)

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

- It is more precise and sensitive than the slump test, and particularly useful for concrete mixes of very low workability.
- Compaction factor (CF) of 0.95 represents flowing concrete having high workability; 0.92 represents plastic concrete having medium workability; 0.85 represents stiff plastic concrete having low workability; and 0.75 represents stiff concrete having very low workability.

Flow Test

- Flow test gives an indication of 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 and the flow or spread of the concrete is measured which relates to workability.
- $\text{Flow } \% = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$
- Flow % values range between 0–150%.

Vee–Bee Consistometer Test

- This test consists of a vibrating table, a metal pot, a sheet metal cone, and a standard iron rod; which measures workability of concrete indirectly.
- A slump cone is prepared and placed inside the sheet metal cylindrical pot of the consistometer.
- Concrete is then vibrated and the time required for change in shape of concrete from conical to cylindrical shape is measured.
- The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as 'Vee-Bee degree'.

  Very low workability > 20 seconds.

  Low: 6–12 sec.

  Medium: 3–6 sec.

  High: 0–3 sec.
- This method is suitable for very dry concrete whose slump value cannot be measured by slump test.

Various Properties of Concrete

Gain of Strength with Age

- Concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age.
- The quantum of increase depends upon the grade and type of cement, curing and environmental conditions, etc.
- The following shows the relationship between 7 days and 28 days strength.

$$f_{28} = k_2 (f_7)^{k_1}$$

Where

f_7 and f_{28} are strengths at 7 days and 28 days.

k_1 and k_2 are the coefficients, which are different for different cements and curing conditions.

Value of k_1 ranges from 0.3 to 0.8; and k_2 from 3 to 6.

Tensile Strength of Concrete

Flexural strength;

$$f_{cr} = 0.7\sqrt{f_{ck}} \text{ N/mm}^2$$

Where, f_{ck} is characteristic cube compressive strength of concrete.

Elastic Deformation

- Modulus of elasticity is primarily influenced by elastic properties of aggregate and to a lesser extent by conditions of curing and age of the concrete.
- Modulus of elasticity is normally related to compressive strength of the concrete.
- It is the secant modulus obtained from the stress-strain diagram.

$$E_c = 5000\sqrt{f_{ck}}$$

Where, E_c is the short-term modulus of elasticity in N/mm^2.

Shrinkage

- The term 'shrinkage' is used to describe the various aspects of volume changes in concrete due to loss of moisture at various stages.
- The total shrinkage of concrete depends upon the constituents of concrete, size of member and environmental conditions.
- For a given humidity and temperature, total shrinkage of concrete is most influenced by total amount of the water present in the concrete at the time of mixing, to a lesser extent, by the cement content.

NOTE

Approximate value of total shrinkage strain for concrete may taken as 0.0003.

Creep of Concrete

- Creep can be defined as the time dependent part of strain resulting from stress. The gradual increase in strain, without increase in stress, with the time is referred as creep.
- Creep coefficient $= \dfrac{\text{Ultimate creep strain}}{\text{Elastic strain}}$
- Creep of concrete depends on stress in the concrete, age at loading and the duration of loading.
- Ultimate creep strains may be estimated from values of creep coefficient.

Age at Loading	Creep Coefficient
7 days	2.2
28 days	1.6
1 year	1.1

Thermal Expansion

- Coefficient of thermal expansion of concrete depends on the nature of cement, aggregate, cement content, relative humidity and the size of sections.
- An average value of linear thermal expansion of concrete ranges between 5.8×10^{-6} per °C to 14×10^{-6} per °C; and may be generally taken as 9.9×10^{-6} per °C.

Segregation

- Segregation is defined as the separation of constituent materials of concrete.
- Segregation may be classified into the following 3 types:
  (a) Coarse aggregate (CA) separating out or settling down from rest of the matrix.
  (b) The paste or matrix separating away from CA.
  (c) Water being separated out from rest of the materials.
- Segregation leads to not only loss of strength, but also includes all undesirable properties in the hardened concrete due to lack of homogeneity.
- The tendency of segregation can be remedied by proper mixing and handling of concrete, transporting, placing, compacting and finishing.
- It is difficult to measure it quantitatively, but segregation can be easily identified at the time of concreting operation.

Bleeding

- Bleeding is a particular form of segregation in which some of the water from the concrete comes out to the surface of concrete.
- Bleeding is predominantly observed in highly wet mixes, poorly proportioned and insufficiently mixed concretes.
- Sometimes, cement and water comes to top surface. This formation of cement paste at the surface is known as litance.
- It can be reduced by proper proportioning and uniform and complete mixing.
- Use of finely divided pozzolanic materials, air-entraining agents, finer cements or cements with low alkali content reduces bleeding.
- It is found that rich mixes are less susceptible to bleeding than lean mixes.

Tests on Hardened Concrete

Compression Test

- Most common test conducted on hardened concrete to determine the compressive strength of the concrete.
- Standard size of cube specimen: 15 × 15 × 15 cm
- Standard size of cylindrical specimen: 15 cm diameter and 30 cm height.
- Cube strength = 1.25 × Cylinder strength

Modulus of Rupture/Flexural Strength of Concrete

- Specimen used: 15 × 15 × 70 cm prism.
- Systems of loading used:
  (a) Central point loading
  (b) Third-point loading
- Indirect tension test methods includes:
  (a) Cylinder splitting tension test
  (b) Ring tension test
  (c) Double punch test, etc.

Non-Destructive Testing Methods

1. **Surface hardness test:**
   - Include tests based on Williams testing pistol, impact hammers (e.g., Schmidt Rebound hammer) etc.
   - Quick method, measures surface hardness only, but not strength of concrete in its core area.
2. **Ultrasonic pulse velocity (UPV) method:**
   - Concrete strength is assessed by sending ultrasonic pulse waves through the concrete in this method.
   - Pulse ultrasonic digital indicating tester (PUNDIT) is a widely used apparatus to determine UPV of concrete.

Pulse Velocity (km/sec)	Condition of Concrete
> 3.5	Excellent
3.0–3.5	Good
2.5–3.0	Medium
< 2.5	Doubtful

3. **Radioactive and nuclear methods:**
   - These include the x-ray and γ-ray penetration tests of measurement of density and thickness of concrete.
   - Neutron scattering, neutron activation methods are used for cement and moisture content determination.
4. **Magnetic and electric methods:**
   - Magnetic methods determine cover of reinforcement in concrete, whereas electrical methods are used to measure the moisture content and thickness of concrete.
5. Similarly, other methods like, dynamic or vibration tests are used to evaluate durability and uniformity of the concrete; and penetration and pullout techniques are used to measure the penetration and pullout resistance of the concrete.

Mix Design

Mix design can be defined as the process selecting suitable ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength and durability as economically as possible.

The process of selection of relative proportions of cement, sand CA and water, so as to obtain a concrete of desired quality is known as proportioning concrete.

Variables in Proportioning

With the given materials, four variable factors are to be considered while specifying a concrete mix.

1. Water-cement ratio
2. Cement content or cement aggregate ratio
3. Gradation of aggregates
4. Consistency

In general, all four these four factors are inter-related and cannot be chosen or manipulated arbitrarily.

Method of Proportioning

Following are the different methods of proportioning concrete.

1. **Arbitrary method:**
   - In this method, proportions of cement, sand and CA are fixed arbitrarily, e.g., 1 : 2 : 4, 1 : 3 : 6, etc.
   - The general expression for proportions of cement, sand and CA is 1 : n : 2n by volume.
   - The recommended proportions are:
     (a) 1 : 1 : 2 and 1 : 1.2 : 2.4, for very high strength concrete.
     (b) $1 : 1\frac{1}{2} : 3$ and 1 : 2 : 4, for normal work,
     (c) 1 : 3 : 6 and 1 : 4 : 8, for foundations and mass concrete works.
   - The concrete as per IS: 456-2000 is designated in 7 grades, namely, M10, M15, M20, M25, M30, M35 and M40.
   - The letter ‘M’ refers to mix and the number indicates specified compressive strength of that mix at 28 days expressed in N/mm^2.
   - Nominal mixes correspond approximately to the different grades are as follows.
     (a) M5 – 1 : 5 : 10
     (b) M7.5 – 1 : 4 : 8
     (c) M10 – 1 : 3 : 6
     (d) M15 – 1 : 2 : 4
     (e) M20 – 1 : 1.5 : 3
     (f) M25 – 1 : 1 : 2
2. **Fineness modulus method:**
   - Fineness modulus is used to indicate an index number which is roughly proportional to the average size of particle in the entire quantity of aggregates.

- Let 'P' be the desired fineness modulus for a concrete mix of fine and coarse aggregates, then:

$$R = \frac{P_2 - p}{P - P_1} \times 100$$

Where
R = Proportions of FA to the combined aggregate by weight
P_1 = Fineness modulus of FA
P_2 = Fineness modulus of CA

3. **Water-cement ratio method:**
   - According to Abram's water-cement ratio, the strength of well-compacted concrete with good workability is dependent only on the water-cement ratio.
   - Optimum water-cement ratio for concrete of required compressive strength is decided from graphs which were developed from various experiments.

The following are the important points in connection with water-cement ratio.

1. Strength of concrete is inversely proportional to the water-cement ratio.
2. Thumb rules for deciding quantity of water in concrete is as follows:
   (a) Weight of water = 28% weight of cement + 4% weight of total aggregate.
   (or)
   (b) Weight of water = 30% of cement + 5% weight of total aggregate.

Indian Standard Method of Concrete Mix Proportioning

The IS method of concrete mix design (IS 2062–1982) guidelines are given as follows:

Step 1: Calculate target mean strength:

$$f_m = f_{ck} + 1.65S$$

Where
f_m = Target mean compressive strength at 28 days
f_{ck} = Characteristic compressive strength at 28 days
S = Standard deviation

The recommended standard deviations are:
M10–M15: 3.5 Mpa
M20–M25: 4 Mpa
M30–M60: 5 Mpa

Step 2: Selection of water-cement ratio

Step 3: Selection of water content

Step 4: Calculate cement and aggregate contents

Estimating Yield of Concrete

If the proportion of concrete is $a : b : c$, i.e., a – parts of cement, b – parts of sand, and c – parts of CA mixed by volume, the resulting concrete will have a volume of 2/3 $(a + b + c)$.

The volume of concrete can be accurately determined by considering the absolute volumes of various components and volume of entrapped air.

$$\text{Absolute volume} = \frac{\text{Weight of the material}}{\text{Apparent specific gravity}} \times \text{Unit weight of water}$$

Exercises

1. Match List I with List II and select the correct answer using codes given below the lists:

	List I		List II
a.	Fineness of cement	**1.**	Le Chatelier apparatus
b.	Setting time	**2.**	Vicat's needle
c.	Soundness	**3.**	Air-permeability apparatus
d.	Workability	**4.**	Slump cone

Codes:

	a	b	c	d
(A)	1	2	3	4
(B)	3	1	4	2
(C)	3	2	1	4
(D)	1	4	3	2

2. If 'p' is the standard consistency of cement, the amount of water used in conducting the initial setting time on cement is
   (A) $0.65p$
   (B) $0.85p$
   (C) $0.6p$
   (D) $0.8p$

3. Gypsum is used as an admixture in cement grouts for
   (A) accelerating the setting time.
   (B) retarding the setting time.
   (C) increasing the plasticity.
   (D) reducing the grout shrinkage.

4. Consider the following statements:
   High early strength of cement is obtained as a result of
   I. fine grinding.
   II. decreasing the lime content.
   III. burning at higher temperatures.
   IV. increasing the quantity of gypsum.
   Which of these statements are correct?
   (A) I and II
   (B) I and III
   (C) II, III and IV
   (D) I, III and IV

5. Match List I (Type of cement) with List II (Characteristics) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Ordinary Portland cement	1.	The percentage of C_3S is maximum and is of the order of 50%
b.	Rapid hardening cement	2.	The percentages of C_2S and C_3S are the same and of the order of 40%
c.	Low heat cement	3.	Reacts with silica during burning and causes particles to unite together and development of strength
d.	Sulphate resistant cement	4.	The percentage of C_3A is minimum and of the order < 5%.

Codes:

	a	b	c	d		a	b	c	d
(A)	2	4	1	3	(B)	3	1	4	2
(C)	2	1	4	3	(D)	3	4	1	2

6. The proper size of mould for testing compressive strength of cement is
(A) 7.05 cm cube
(B) 10.05 cm cube
(C) 15 cm cube
(D) 12.05 cm cube

7. In cements, generally the increase in strength during a period of 14 days to 28 days is primarily due to
(A) C_3A (B) C_2S
(C) C_3S (D) C_4AF

8. Fineness of cement is measured in the units of
(A) volume/mass (B) mass/volume
(C) area/mass (D) mass/area

9. One bag of Portland cement, 50 kg in weight, would normally have a bulk volume of
(A) 30 litres (B) 35 litres
(C) 40 litres (D) 45 litres

10. The approximate ratio between the strengths of cement concrete at 7 days and at 28 days is
(A) $\frac{3}{4}$ (B) $\frac{2}{3}$
(C) $\frac{1}{2}$ (D) $\frac{1}{3}$

11. 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) $33\frac{1}{3}\%$
(C) 50% (D) $66\frac{2}{3}\%$

12. Match List I (Admixtures) with List II (Chemicals) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Water-reducing admixture	1.	Sulphonated melanin formaldehyde
b.	Air-entraining agent	2.	Calcium chloride
c.	Superplasticiser	3.	Lignosulphonate
d.	Accelerator	4.	Neutralised vinsol resin

Codes:

	a	b	c	d		a	b	c	d
(A)	2	4	1	3	(B)	1	3	4	2
(C)	3	4	1	2	(D)	3	4	2	1

13. 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

14. While testing the compressive strength of cement concrete, the correct standard conditions (viz., temperature, age, humidity and size of the specimen) to be maintained as per IS are
(A) $27 \pm 3°C$, 28 days, 90% and 15 cm^3
(B) $26 \pm 2°C$, 21 days, 80% and 15 cm^3
(C) $25 \pm 1°C$, 14 days, 75% and 15 cm^3
(D) $27 \pm 3°C$, 7 days, 70% and 10 cm^3

15. Match List I (Workability test) with List II (Measurements) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Slump test	1.	300–500 mm
b.	Compacting factor	2.	75–125 mm
c.	Vee-bee test	3.	0.80 to 0.98
d.	Flow test	4.	0 to 10 s

Codes:

	a	b	c	d		a	b	c	d
(A)	2	4	3	1	(B)	1	3	4	2
(C)	1	4	3	2	(D)	2	3	4	1

16. Which one of the following aggregates gives maximum strength in concrete?
(A) Rounded aggregate
(B) Elongated aggregate
(C) Flaky aggregate
(D) Cubical aggregate

17. Bleeding of concrete leads to which of the following?
I. Drying up of concrete surface.
II. Formation of pores inside.
III. Segregation of aggregate.
IV. Decrease in strength.

Select the correct answer using the codes given below:

(A) I only (B) I and II
(C) I and III (D) II and IV

18. The fineness modulus of the fine aggregate is 2.78 and of coarse aggregate is 7.82 and the desired fineness modulus of mixed aggregate is 6.14. What is the amount of fine aggregate to be mixed with one part of coarse aggregate?

(A) 55% (B) 50%
(C) 45% (D) 40%

19. In a shape test of aggregate, which one of the following gives the correct slot for flakiness index for a material passing 50 mm sieve and retained on 40 mm sieve?

(A) 25 m (B) 27 mm
(C) 81 mm (D) 30 mm

20. Match the sequence of determination of components of a concrete mix as per Indian standard method of mix design and select the correct answer using the codes given below:

	List I		List II
a.	Cement content	**1.**	First step
b.	Aggregate content	**2.**	Second step
c.	Water content	**3.**	Third step
d.	Water-cement ratio	**4.**	Fourth step

Codes:

	a	b	c	d		a	b	c	d
(A)	1	2	4	3	(B)	3	2	4	1
(C)	3	4	2	1	(D)	1	4	2	3

21. The proportion of cement: FA : CA in a given concrete is 1 : 2 : 4; then the mix refers to

(A) M20 (B) M15
(C) M10 (D) M5

22. Which of the following pairs are incorrect with reference to ordinary Portland cement?

I. Initial setting time—30 minutes
II. Final setting time—10 hours
III. Normal consistency—10%
IV. All are correct

(A) IV (B) II and III
(C) III only (D) I and III

23. The most commonly used admixture to accelerate the initial setting time of concrete is _____.

(A) gypsum (B) calcium carbonate
(C) calcium chloride (D) calcium ferrate

24. A sand is said to be unsuitable for construction if it has FM more than ______

(A) 2.9 (B) 3.2
(C) 3.4 (D) 3.9

25. The standard size of specimen for conducting the modules of rupture of concrete is

(A) 15 × 15 × 60 cm (B) 15 × 15 × 65 cm
(C) 15 × 15 × 70 cm (D) 15 × 15 × 75 cm

26. To make one cubic meter of 1 : 2 : 4 by volume centrete, the volume of coarse aggregate required is _____.

(A) 0.95 m^3 (B) 0.85 m^3
(C) 0.75 m^3 (D) 0.65 m^3

27.

	List I		List II
1.	Setting time of cement	**a.**	Le Chatelier's apparatus
2.	Consistency of cement	**b.**	Air-permeability test
3.	Soundness of cement	**c.**	Vicat apparatus
4.	Fineness	**d.**	Pycnometer

Choose the correct one from the following

(A) 1 – c, 2 – c, 3 – b, 4 – a
(B) 1 – c, 2 – a, 3 – a, 4 – d
(C) 1 – c, 2 – c, 3 – a, 4 – b
(D) 1 – c, 2 – a, 3 – a, 4 – d

28.

Type of Work	Slump Recommended
Concrete for road works	20–28 mm
Ordinary RCC work	50–100 mm
Mass concrete	75–175 mm
Columns–retaining walls	12–25 mm

Which of the following pairs are correctly matched

(A) 1, 3 and 4 (B) 1 and 3
(C) 3 and 4 (D) 2 and 4

29. The fineness modulus of CA and FA are given as 7.6 and 2.78 respectively. The economical value of fineness modulues of combined aggregate is 6.4, then the proportion of fine aggregate is ________

(A) 25% (B) 33.33%
(C) 50% (D) 66.67%

30. Considering following strengths of concrete, choose the correct sequence in increasing order.

I. Cube strength
II. Cylinder strength
III. Split tensile strength
IV. Modulus of rupture

(A) III, IV, II, I (B) III, IV, I, II
(C) IV, III, II, I (D) IV, III, I, II

31. UPV method of non-destructive testing for concrete is used to determine _______.

I. compressive strength
II. existence of voids
III. tensile strength
IV. static modulus of concrete
V. dynamic modulus of concrete

(A) I, II, III and IV (B) I and III only
(C) II and V only (D) III and V only

32. In shape test of aggregate which one of the following gives the correct slot for flakiness index for a material passing 50 mm sieve and retained on 40 mm sieve?

(A) 25 mm (B) 27 mm
(C) 81 mm (D) 30 mm

33. Identify the sequence of determination of components of a concrete mix as per IS method of mix design select the correct answer using codes given below.

	List I		List II
a.	Cement content	**1.**	First step
b.	Aggregate content	**2.**	Second step
c.	Water content	**3.**	Third step
d.	Water cement ratio	**4.**	Fourth step

a b c d a b c d

(A) 1 2 3 4 (B) 3 2 4 1

(C) 1 4 2 3 (D) 3 4 2 1

34. Match List I with List II

	List I (Cement Mortar for Different Works)		List II (Cement: Sand in Mortar)
a.	For normal brick work	**1.**	1 : 4
b.	For plastering work	**2.**	1 : 3
c.	For grouting the cavernous rocks	**3.**	1 : 6
d.	For guniting	**4.**	1 : 1.5

Codes:

a b c d a b c d

(A) 3 2 4 1 (B) 4 1 3 2

(C) 4 2 3 1 (D) 3 1 4 2

35. The following test is conducted to determine the strength of hardened existing concrete?

(A) Bullet test
(B) Kelly ball test
(C) Rebound hammer test
(D) Cone penetrometer

36. In a concrete mix, if maximum size of coarse aggregate is increased, the proportion of fine to coarse aggregate should be ______.

(A) increased (B) decreased
(C) remains same (D) no relevance to size

37. The correct sequence of workability test(s) in order of their application from low to high workability is ______.

(A) slump test, compacting factor test and vee-bee consistometer
(B) Vee-bee consistometer, slump test and compacting factor test
(C) Vee-bee consistometer, compacting factor test and slump test
(D) compacting factor test, vee-bee consistometer and slump test

38. What is the quantity of cement (in kg) and of dry sand (in m^3) respectively required for preparing 1 m^3 of wet cement mortar of 1 : 5 proportion?

(A) 270 and 1.0 (B) 290 and 1.05
(C) 290 and 1.0 (D) 310 and 1.05

39. If aggregate size of 50–40 mm is to be tested for determining the proportion of elongated aggregates, the slot length of guage should be ______.

(A) 45 mm (B) 53 mm
(C) 81 mm (D) 90 mm

40. Which one of the following statement(s) are incorrect?

(A) Adding 5% to 6% moisture by weight increases the volume of dry sand from 18% to 38%.
(B) The bulking of fine sand is more than that of coarse sand.
(C) Volume of fully saturated fine sand is equal to that of dry sand.
(D) All are correct

41. Shrinkage of concrete depends upon ______.

(A) relative humidity of the atmosphere
(B) passage of time
(C) applied stress
(D) Both (A) and (B)

42. Consider the following statements.

I. Bleeding indicates deficiency of coarse material in the mix.
II. Segregation indicates poor aggregate grading.
III. Curing of concrete by steam pressure increases the compressive strength of concrete.
IV. Curing under steam pressure increases the rate of gain of compressive strength.

Which of the following statements are correct?

(A) I, II and III (B) II, IV only
(C) II, III and IV (D) I, II and IV

43. For compressive strength determination the minimum number of cubes required in a sample are

(A) 1 (B) 2
(C) 3 (D) 5

44. Gypsum consists of

(A) H_2S and CO_2
(B) $CaSO_4$ and H_2O
(C) Lime and H_2O
(D) CO_2 and cascium

45. To prepare 1 m^3 of 1 : 1.5 : 3 concrete for foundation work. The total amount of aggregate required in m^3 is ________.

(A) 0.82 m^3 (B) 0.41 m^3
(C) 1.23 m^3 (D) 1.5 m^3

Previous Years' Questions

1. Workability of concrete can be measured using slump, compaction factor and Vee–Bee time. Consider the following statements for workability of concrete: **[GATE, 2015]**

I. As the slump increases, the Vebe time increases.

II. As the slump increases, the compaction factor increases.

Which of the following is TRUE?

(A) Both I and II are True
(B) Both I and II are False
(C) I is True and II is False
(D) I is False and II is True

2. Consider the following statements for air-entrained concrete: **[GATE, 2015]**

I. Air-entrainment reduces the water demand for a given level of workability.

II. Use of air-entrained concrete is required in environments where cyclic freezing and thawing is expected

Which of the following is TRUE?

(A) Both I and II are True
(B) Both I and II are False
(C) I is True and II is False
(D) I is False and II is True

3. The composition of an air-entrained concrete is given below:

Water: 184 kg/m^3

Ordinary Portland Cement (OPC): 368 kg/m^3

Sand: 606 kg/m^3

Coarse aggregate : 1155 kg/m^3

Assume the specific gravity of OPC, sand and coarse aggregate to be 3.14, 2.67 and 2.74, respectively. The air content is ______ lit/m^3. **[GATE, 2015]**

4. The compound which is largely responsible for initial setting and early strength gain of Ordinary Portland Cement is **[GATE, 2016]**

(A) C_3A
(B) C_3S
(C) C_2S
(D) C_4AF

Answer Keys

Exercises

1. C	**2.** B	**3.** B	**4.** B	**5.** B	**6.** A	**7.** C	**8.** C	**9.** B	**10.** B
11. B	**12.** C	**13.** B	**14.** A	**15.** D	**16.** D	**17.** D	**18.** B	**19.** B	**20.** C
21. B	**22.** C	**23.** C	**24.** B	**25.** C	**26.** B	**27.** C	**28.** B	**29.** B	**30.** A
31. C	**32.** B	**33.** D	**34.** D	**35.** C	**36.** B	**37.** C	**38.** D	**39.** C	**40.** D
41. D	**42.** B	**43.** C	**44.** B	**45.** C					

Previous Years' Questions

1. D	**2.** A	**3.** 51	**4.** B