MODULE 6

SPECIAL CONCRETES

LIGHTWEIGHT CONCRETE

- One of the disadvantage of conventional concrete is the **high self weight of concrete**.
- Density of the normal concrete is in the order of **2200 to 2600 kg/m^3** .
- The light-weight concrete as we call is a concrete whose density varies from **300 to 1850 kg/m^3**.
- Advantages of having low density: -----
  - ✓ It helps in **reduction of dead load**, increases the progress of building, and lowers haulage and handling costs. The weight of a building on the foundation is an important factor in design, particularly in the case of weak soil and tall structures. In framed structures, the beams and columns have to carry load of floors and walls. If floors and walls are made up of light-weight concrete it will result in considerable economy.

- ✓ Another most important characteristic of light-weight concrete is the **relatively low thermal conductivity**, a property which improves with decreasing density. In extreme climatic conditions and also in case of buildings where air-conditioning is to be installed, the use of light-weight concrete with low thermal conductivity will be of considerable advantage from the point of view of thermal comforts and lower power consumption.
- ✓ The adoption of light-weight concrete gives an **outlet for industrial wastes** such as clinker, fly ash, slag etc. which otherwise create problem for disposal.
- ➢ Basically there is only **one method** for making concrete light i.e. , by the **inclusion of air in concrete**. This is achieved in actual practice by three different ways: ----

(a) By replacing the usual mineral aggregate by cellular porous or light-weight aggregate.

(b) By introducing gas or air bubbles in mortar. This is known as **aerated concrete**.

(c) By omitting sand fraction from the aggregate. This is called **'no-fines' concrete**.

- A particular type of light-weight concrete called **structural light-weight concrete** is the one which is comparatively lighter than conventional concrete but at the same time strong enough to be used for structural purposes. It, therefore, combines the advantages of normal weight concrete and discards the disadvantages of normal weight concrete.

Table 12.1. Groups of Light-weight Concrete

No-fines Concrete	Light-weight aggregate concrete	Aerated Concrete	
		Chemical aerating	*Foaming mixture*
(a) Gravel (b) Crushed stone (c) Coarse clinker (d) Sintered pulverised fuel ash (e) Expanded clay or shale (f) Expanded slate (g) Foamed Slag	(a) Clinker (b) Foamed slag (c) Expanded clay (d) Expanded shale (e) Expanded slate (f) Sintered pulverised fuel ash (g) Exfoliated vermiculite (h) Expanded perlite (i) Pumice (j) Organic aggregate	(a) Aluminium powder method (b) Hydrogen peroxide and bleaching powder method	(a) Preformed foam (b) Air-entrained foam

- Out of the three main groups of light-weight concrete, the light-weight aggregate concrete and aerated concrete are more often used than the ‘no-fines’ concrete.
- Light-weight concrete can also be classified on the purpose for which it is used, such as **structural light weight concrete, non-load bearing concrete and insulating concrete**.
- The aerated concrete which was mainly used for insulating purposes is now being used for structural purposes sometimes in conjunction with steel reinforcement.

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Light Weight Aggregate (LWA) concrete

- Very often light-weight concrete is made by the use of light weight aggregates.
- Strength of light-weight concrete depends on the density of concrete.
- The different light-weight aggregates have different densities.
- Light-weight aggregates can be classified into two:
- **Natural light-weight aggregates**
- **Artificial light-weight aggregates.**

Natural light-weight aggregate	*Artificial light-weight aggregate*
(*a*) Pumice	(*a*) Artificial cinders
(*b*) Diatomite	(*b*) Coke breeze
(*c*) Scoria	(*c*) Foamed slag
(*d*) Volcanic cinders	(*d*) Bloated clay
(*e*) Sawdust	(*e*) Expanded shales and slate
(*f*) Rice husk	(*f*) Sintered fly ash
	(*g*) Exfoliated vermiculite
	(*h*) Expanded perlite
	(*i*) Thermocole beads

Aerated Concrete

- Made by **introducing air or gas into a slurry** composed of Portland cement or lime and finely crushed siliceous filler so that when mix sets and hardens , a uniformly cellular structure is formed
- Concrete is a mixture of water, cement and finely crushed sand
- Also called as gas concrete, foam concrete and cellular concrete

There are several ways in which aerated concrete can be manufactured

1. By formation of gas by chemical reaction within the mass during liquid or plastic state
2. By mixing preformed stable foam with the slurry
3. By using finely powdered metal (aluminium) with the slurry and made to react with calcium hydroxide liberated during hydration process to give out large quantity of hydrogen gas. This hydrogen gas when contained in the slurry mix gives the cellular structure

No – fines Concrete

- No fines concrete is a kind of concrete from which the fine aggregate fraction has been omitted.
- The concrete is made up of CA, cement and water only
- Very often single sized CA of size passing 20mm and retained on 10mm is used
- The single sized aggregates make a good no-fines concrete, which in addition to having large voids and hence light weight, also offers architectural attractive look.

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Uses of LWC

- Heat insulation on walls
- Construction of partition walls and panel walls in framed structures
- Casting structural steel to protect it against fire and corrosion or as a covering for architectural purposes
- Insulating water pipes
- General insulative walls
- Also used for reinforced concrete structures

HIGH STRENGTH CONCRETE

- Concrete is generally classified as **Normal Strength Concrete (NSC), High Strength Concrete (HSC) and Ultra High Strength Concrete (UHSC).** There are no clear cut boundary for the above classification. Indian Standard Recommended Methods of Mix Design denotes the boundary at 35 MPa between NSC and HSC. In the international forum, the high strength lable was applied to concrete having strength above 40 MPa. More recently, the threshold rose to 50 to 60 MPa.
- In the world scenario, however, in the last 15 years, concrete of very high strength entered the field of construction, in particular construction of **high-rise buildings and long span bridges.** Concrete strengths of 90 to 120 MPa are occasionally used. The advent of Prestressed Concrete Technology Techniques has given impetus for making concrete of higher strength. In India, there are cases of using high strength concrete for prestressed concrete bridges.

- With the modern equipments, understanding of the role of the constituent materials, production of high strength concrete has become a routine matter.
- HSC is made by lowering w/c ratio to 0.35 or lower. Due to low w/c ratio it causes problem of placing, to overcome this super plasticizers are used.
- There are special methods of making high strength concrete. They are given below: ---
  - (a) Seeding (b) Revibration (c) High speed slurry mixing; (d) Use of admixtures (e) Inhibition of cracks (f) Sulphur impregnation (g) Use of cementitious aggregates.

Seeding:

- This involves adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix.

Revibration:

- Concrete undergoes plastic shrinkage. Mixing water creates continuous capillary channels, bleeding, and water accumulates at some selected places. All these reduce the strength of concrete. Controlled revibration removes all these defects and increases the strength of concrete.

High Speed slurry mixing:

- This process involves the advance preparation of cement water mixture which is then blended with aggregate to produce concrete. Higher compressive strength obtained is attributed to more efficient hydration of cement particles and water achieved in the vigorous blending of cement paste.

Use of Admixtures:

- Use of water reducing agents are known to produce increased compressive strengths.

Inhibition of cracks:

- Concrete fails by the formation and propagation of cracks. If the propagation of cracks is inhibited, the strength will be higher. Replacement of 2– 3% of fine aggregate by polythene or polystyrene lenticules results in higher strength. They appear to act as crack arresters without necessitating extra water for workability. Concrete cubes made in this way have yielded strength upto 105 MPa.

Sulphur Impregnation:

- Satisfactory high strength concrete have been produced by impregnating low strength porous concrete by sulphur. The process consists of moist curing the fresh concrete specimens for 24 hours, drying them at 120°C for 24 hours, immersing the specimen in molten sulphur under vacuum for 2 hours and then releasing the vacuum and soaking them for an additional ½ hour for further infiltration of sulphur. The sulphur-infiltrated concrete has given strength upto 58 MPa.

Use of Cementitious aggregates:

- It has been found that use of cementitious aggregates has yielded high strength. Cement fondu is kind of clinker. This glassy clinker when finely ground results in a kind of cement. When coarsely crushed, it makes a kind of aggregate known as ALAG. Using Alag as aggregate, strength upto 125 MPa has been obtained with w/c ratio 0.32.

APPLICATIONS OF HSC:

- Use of HSC in column section decreases the column size
- Use of HSC in column decreases the amount of steel required for the same column
- In high rise building, use of HSC increases the floor area for rental purpose
- In bridges, use of HSC reduces the number of beams supporting the slab

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Roller Compacted Concrete

- Roller compacted concrete is a special blend of concrete that has essentially the same ingredients as conventional concrete but in different ratios and increasingly with partial substitution of flyash for Portland cement.
- A mixture of aggregates, cement and water are mixed in a conventional batch mixer or in other suitable mixers.
- Supplementary cementing material, such as fly ash can also be used.
- In some cases high volume fly ash to the extent of 60% by weight of cement has been used.
- The cement content ranges from 60 to 360 kg/m^3.
- Roller compacted concrete is placed in layers thin enough to allow complete compaction.
- The optimum layer thickness ranges from 20 to 30 cm.

- To ensure adequate bonding between the new and old layer, segregation must be prevented and a high plasticity bedding mix must be used at the start of the placement.
- A compressive strength of about 7MPa to 30 MPa have been obtained.
- For effective consolidation, roller compacted concrete must be dry enough to support the mass of the vibrating equipment, but wet enough to allow the cement paste to be evenly distributed throughout the mass during mixing and consolidation process.

Ready Mix concrete

- It refers to concrete that is batched for delivery from a central plant instead of being mixed on the job site
- Ready-mix concrete, or RMC as it's also known, refers to concrete that is specifically batched or manufactured for customers' construction projects.
- It is a mixture of Portland cement, water, FA and CA.
- Ready-mix concrete is batched or manufactured under controlled conditions.
- It is delivered to the contractors in plastic condition usually in trucks known as **transit mixers**
- The RMC supplies two services,

1. **Processing the materials for making fresh concrete**
2. **Transporting a product within short time**

Advantages of RMC

- A centralized plant can serve wide area
- Better quality control is ensured
- Elimination of storage space for basic materials at site
- Elimination of hiring plant and machinery
- Wastage of basic materials is avoided
- Labours associated with production of concrete is eliminated
- Time required is greatly reduced
- Noise and dust pollution at site is reduced

Disadvantages of RMC

- Materials are combined in a batch plant, and the hydration process begins at the moment water meets the Portland cement, so the travel time from the plant to the site is critical over longer distances.
- Access roads and site access have to be able to carry the greater weight of the ready-mix truck plus load.
- Concrete has a limited lifespan between batching / mixing and placing. This means that ready-mix should be placed within 30 to 45 minutes of batching process to hold slump and mix design specifications. Modern admixtures and plasticizer and water reducers can modify that time span. The amount and type of admixture added to the mix is very important.

Polymer Concrete

- Polymer concrete is a composite where polymer replaces the cement water matrix in the cement concrete.
- This is then polymerized either at room temperature or at an elevated temperature
- The polymer binds the aggregate to give strong composite
- The impregnation of monomer and subsequent polymerisation is the latest technique adopted to reduce the inherent porosity of the concrete, to improve the strength and other properties of concrete.

Types of Polymer concrete

1. Polymer impregnated concrete (PIC)
2. Polymer cement concrete (PCC)
3. Polymer concrete (PC)
4. Partially impregnated and surface coated polymer concrete

1. **<u>Polymer impregnated concrete</u> (PIC)**

- Polymer impregnated concrete is one of the widely used polymer composite.
- It is a precast conventional concrete, cured and dried in oven, or by dielectric heating.
- Then a low viscosity monomer is diffused and polymerised by using radiation, application of heat or by chemical initiation.
- Mainly the following types of monomer are used:

  (a) Methylmethacrylate (MMA),

  (b) Styrene,

  (c) Acrylonitrile,

  (d) t-butyl styrene,

  (e) Other thermoplastic monomers.

2. Polymer cement concrete (PCC)

- Polymer cement concrete is made by mixing cement, aggregates, water and monomer.
- Such plastic mixture is cast in moulds, cured, dried and polymerised.
- The monomers that are used in PCC are:

  (a) Polyster-styrene.

  (b) Epoxy-styrene.

  (c) Furans.

  (d) Vinylidene Chloride.

- However, the results obtained by the production of PCC in this way have been disappointing and have shown relatively modest improvement of strength and durability.
- In many cases, materials poorer than ordinary concrete are obtained.
- This behaviour is explained by the fact that organic materials (monomers) are incompatible with aqueous systems and sometimes interfere with the alkaline cement hydration process.

3. **<u>Polymer concrete</u> (PC)**

- Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement as in conventional concrete.
- The main technique in producing PC is to minimise void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates.
- This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume.
- The graded aggregates are prepacked and vibrated in a mould.
- Monomer is then diffused up through the aggregates and polymerisation is initiated by radiation or chemical means.

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4. Partially impregnated and surface coated polymer concrete

- Partial impregnation may be sufficient in situations where the major requirement is surface resistance against chemical and mechanical attack in addition to strength increase. Even with only partial impregnation, significant increase in the strength of original concrete has been obtained.
- It is produced by initially soaking the dried specimens in liquid monomer like methyl methacrylate, then sealing them by keeping them under hot water at 70°C to prevent or minimise loss due to evaporation.
- The polymerisation is done by adding three per cent by weight of benzoyl peroxide to the monomer as a catalyst.
- It is seen that the depth of monomer penetration is dependent upon following:

(a) Pore structure of hardened and dried concrete.

(b) The duration of soaking, and

(c) The viscosity of the monomer.

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Self Compacting Concrete

- Self compacting concrete is a highly flowable type of concrete that spreads in to the form without the need of mechanical vibrations. It is placed by its own weight.
- It has proved to be beneficial from the following points.

- Faster construction
- Reduction in site manpower
- Better surface finish
- Easier placing
- Improved durability
- Greater freedom in design
- Thinner concrete sections
- Reduced noise level

Self Compacting Concrete (SCC)

Material for SCC

Cement : Ordinary Portland Cement, 43 or 53 grade can be used.

Aggregates : The maximum size of aggregate is generally limited to 20 mm. Fine aggregates can be natural or manufactured. Particles smaller than 0.125 mm i.e. 125 micron size are considered as FINES which contribute to the powder content.

Mixing Water :

Chemical Admixtures : Superplaseizers are an essential component of SCC to provide necessary workability. The new generation superplasticizers termed poly-carboxylated ethers (PCE) is particularly useful for SCC. Other types such as Viscosity Modifying Agents (VMA) for stability, air entraining agents (AEA) to improve freeze-thaw resistance, and retarders for control of setting.

Mineral Admixtures:

Fly ash, Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume, Stone Powder, Fibres

A concrete mix can only be classified as self compacting if it has the following characteristics

- Filling Ability
- Passing ability
- Seggregation resistance

Production and placing

Mixing : Any suitable mixer could be used - Generally, mixing time need to be longer than for conventional concrete. It is recommended that every batch must be tested until consistent and compliant results are obtained.

Placing: Formwork must be in good conditions to prevent leakage. Though it is easier to place SCC than ordinary concrete, the following rules are to be followed to minimise the risk of segregation.

- limit of vertical free fall distance to 5 meter.
- limit the height of pour lifts (layers) to 500 mm
- limit of permissible distance of horizontal flow from point of discharge to 10 meters.

Curing: On account of no bleeding or very little bleeding, SCC tends to dry faster and may cause more plastic shrinkage cracking. Therefore, initial curing should be commenced as soon as practicable. Alternatively the SCC must be effectively covered by polyethylene sheet. Due to the high content of powder, SCC can show more plastic shrinkage or creep than ordinary concrete mixes.

FIBRE REINFORCED CONCRETE

- Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking.
- Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such microcracks, eventually leading to brittle fracture of the concrete.
- In plain concrete and similar brittle materials, structural cracks (micro-cracks) develop even before loading, particularly due to drying shrinkage or other causes of volume change.
- The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be of higher magnitude.
- It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete.
- Fibre is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fibre is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fibre is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.

- "Fibre reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres."
- Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres

FIBRES USED

Although every type of fibre has been tried out in cement and concrete, not all of them can be effectively and economically used. Each type of fibre has its characteristic properties and limitations. Some of the fibres that could be used are steel fibres, polypropylene, nylons, asbestos, coir, glass and carbon.

- **Steel fibre** is one of the most commonly used fibre. Generally, round fibres are used. The diameter may vary from 0.25 to 0.75 mm. The steel fibre is likely to get rusted and lose some of its strengths. But investigations have shown that the rusting of the fibres takes place only at the surface. Use of steel fibre makes significant improvements in flexural, impact and fatigue strength of concrete, It has been extensively used in various types of structures, particularly for overlays of roads, airfield pavements and bridge decks.
- **Polypropylene and nylon fibres** are found to be suitable to increase the impact strength. They possess very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to the flexural strength.

- **Asbestos** is a mineral fibre and has proved to be most successful of all fibres as it can be mixed with Portland cement. Tensile strength of asbestos varies between 560 to 980 N/mm^2. The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste.
- For unimportant fibre concrete, organic fibres **like coir, jute, canesplits** are also used.
- **Glass fibre** is a recent introduction in making fibre concrete. It has very high tensile strength 1020 to 4080 N/mm2.
- **Carbon fibres** perhaps posses very high tensile strength 2110 to 2815 N/mm^2 and Young's modulus. It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength. The limited studies have shown good durability. The use of carbon fibres for structures like clading, panels and shells will have promising future.

Factors Effecting Properties of Fibre Reinforced Concrete

The efficient transfer of stress between matrix and the fibres largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate. These factors are briefly discussed below:

- **Relative Fibre Matrix Stiffness**

The modulus of elasticity of matrix must be much lower than that of fibre for efficient Stress transfer. *Low modulus* of fibers such as nylons and polypropylene are, therefore, Unlikely to give strength improvement, but they help in the absorption of large energy and therefore, impart greater degree of toughness and resistance to Impact. *High modulus* Fibres such as steel, glass and carbon impart strength and stiffness to the composite.

- **Volume of Fibres**

The strength of the composite largely depends on the quantity of fibres used in it. It can be seen that the increase in the volume of fibres, increase approximately linearly, the tensile strength and toughness of the composite. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.

Aspect Ratio of the Fibre

Another important factor which influences the properties and behaviour of the composite is the aspect ratio of the fibre. It has been reported that upto aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced.

Orientation of Fibres

One of the differences between conventional reinforcement and fibre reinforcement Is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented. fibres aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibres.

Workability and Compaction of Concrete

Incorporation of steel fibre decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fibre volume at which this situation is reached depends on the length and diameter of the fibre. Another consequence of poor workability is non-uniform distribution of the fibres

- **Size of Coarse Aggregate**

Maximum size of the coarse aggregate should be restricted to 10 mm, to avoid appreciable reduction in strength of the composite. Fibres also in effect, act as aggregate.

Mixing

Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation, and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendencies . This can be done by the addition of fibres before the water is added. When mixing in a laboratory mixer,introducing the fibres through a wire mesh basket, will help even distribution of fibres. For field use, other suitable methods must be adopted

Applications

- Fibre reinforced concrete is increasingly used on account of the advantages of increased static and dynamic tensile strength, energy absorbing characteristics and better fatigue strength.
- The uniform dispersion of fibres throughout the concrete provides isotropic properties not common to conventionally reinforced concrete.
- Fibre reinforced concrete has been tried on overlays of air-field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings etc.
- The fibre reinforced concrete can also be used for the fabrication of precast products like pipes, boats, beams, stair case steps, wall panels, roof panels, manhole covers etc...
- Fibre reinforced concrete in also being tried for the manufacture of prefabricated formwork moulds of “U” shape for casting lintels and small beams.

SPRAYED CONCRETE/ The Gunite or Shotcrete

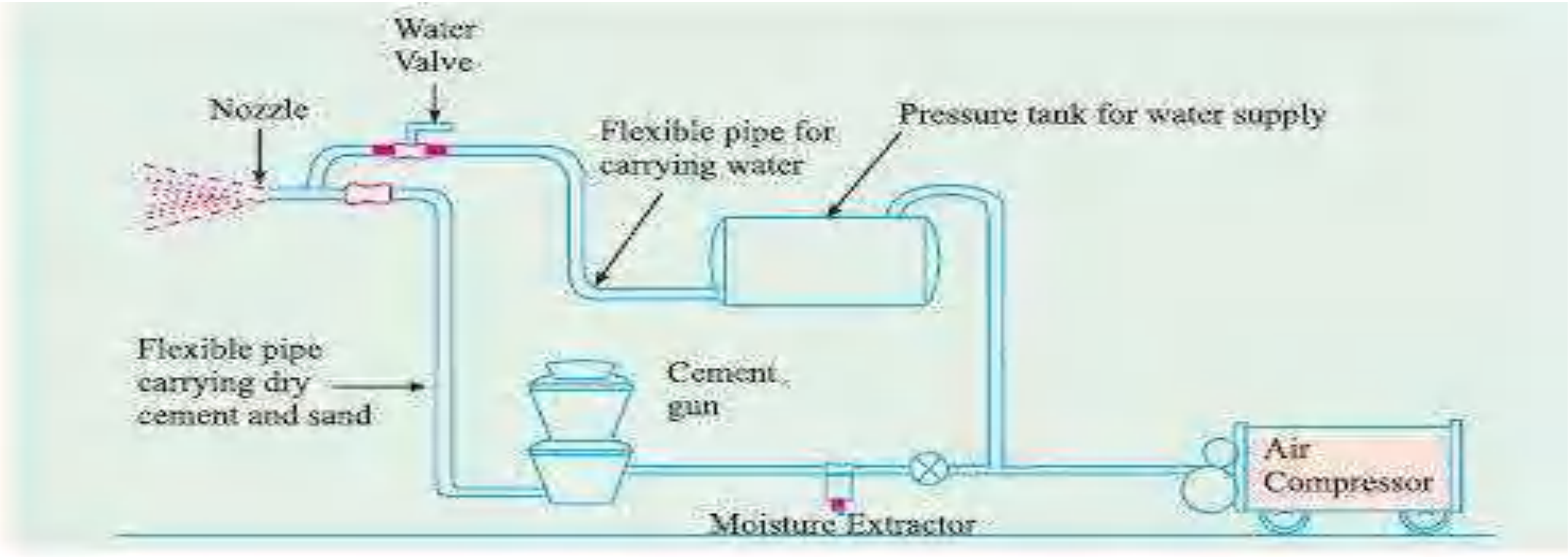
- Gunite can be defined as mortar conveyed through a hose and pneumatically projected at a high velocity on to a surface.
- Recently the method has been further developed by the introduction of small sized coarse aggregate into the mix deposited to obtain considerably greater thickness in one operation and also to make the process economical by reducing the cement content.
- Normally fresh material with zero slump can support itself without sagging or peeling off.
- The force of the jet impacting on the surface compact the material. Sometimes use of set accelerators to assist overhead placing is practiced.
- There is not much difference between guniting and shotcreting. **Guniting** is mostly used for pneumatical application of mortar of less thickness, whereas **shotcrete** is a recent development on the similar principle of guniting for achieving greater thickness with small coarse aggregates.

METHODS

- There are two different processes in use, namely the “Wet-mix” process and the “dry-mix”process. The dry mix process is more successful and generally used.

The Dry-mix Process

- The dry mix process consists of a number of stages and calls for some specialised plant. The stages involved in the dry mix process is given below:
- Cement and sand are thoroughly mixed.
- The cement/sand mixture is fed into a special air-pressurized mechanical feeder termed as ‘gun’.
- The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.
- This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.
- The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.



A typical small plant set-up for dry process is shown in Fig.

The Wet-mix Process

In the wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by compressed air, onto the work in the same way, as that of dry mix process.
The wet-mix process has been generally discarded in favour of the dry-mix process, owing to the greater success of the latter.

Advantages of Wet and Dry Process

Some of the advantages and disadvantages of the wet and dry processes is discussed below.

- It is possible to obtain more accurate control of the w/c ratio with the wet process
- The difficulty of pumping light-weight aggregate concrete makes the dry process more suitable when this type of aggregate is used.
- The dry process on the other hand, is very sensitive to the water content of the sand, too wet a sand causes difficulties through blockade of the delivery pipeline, a difficulty which does not arise with the wet process.
- The lower w/c ratio obtained with the dry process probably accounts for the lesser creep and greater durability of concrete produced in this way compared with concrete deposited by the wet process, but air-entraining agents can be used to improve the durability of concrete deposited by the latter means.
- Admixtures generally can be used more easily with the wet process except for accelerators.
- Wet process does not normally give such a dense concrete as the dry process.
- Work can be continued in more windly weather with the wet process than with the dry process
- Owing to the high capacities obtainable with concrete pumps, a higher rate of laying of concrete can probably be achieved in the wet process than with the dry process.

General Use of Shotcrete

- The high cost of shotcrete limits its application to certain special circumstances where considerable savings are accrued and where its peculiar adaptability and technical advantages render it more suitable than conventional placing methods.
- Shuttering and formwork need be erected only on one side of the work and it does not have to be so strong as the shuttering for poured concrete.
- It can be conveyed over a considerable distance in a small diameter pipe makes this process suitable for sites where access is difficult. The other method that can be adopted in such situation is pumping techniques.
- The quality of the finished product is liable to be variable and particularly in the dry process the quality is very much dependent on the skill of the nozzleman. It is difficult to obtain a satisfactory surface finish with Shotcrete, particularly with the dry process, because it is almost impossible to trowel due to the low water content. Often it becomes necessary to apply a screed of about 2 cm over the gunited surface.
- The application of the shotcrete process is limited to exceptional areas and that too when good nozzleman having the required skill are available.
- Admixtures can be used in shotcrete to produce the same effects as in ordinary concrete. They should be added to the water in the dry process.
- There is not much information on the drying shrinkage and creep of shotcrete. The drying shrinkage will be fairly low for the dry process. The shrinkage and creep of wet shotcrete is likely to be high.
- The durability or resistance to frost action and other agencies of dry shotcrete is good. It is not so good for wet shotcrete but can be improved to a satisfactory degree by the use of air-entraining agents. About half of the entrained air is likely to be lost while spraying.

MASS CONCRETE

- The concrete placed in massive structures like dams, piers, bridges etc can be termed as mass concrete. Longer size aggregates (upto 150mm) and low slmp areadopted.
- The mix is harsh and dry and requires power vibrators.
- Mass concrete is made with solid structures (> 80 cm). These structures frequently contain a greater volume.
- It signifies that large volumes of concrete should be set up in a short time. It needs highly well-organized planning and competent methods.

Applications:

- Foundations for large loads
- Foundations for buoyancy control
- Solid walls (e.g. radiation protection)
- Infill concrete

The following **major issues** are formed with these enormous structures:

- Extreme internal and external temperature discrepancies throughout setting and hardening
- Excessive maximum temperatures
- High internal and external temperature deviations and as a result forced shrinkage
- Secondary consolidation (settling) of the concrete and as a result cracking occurs over the top reinforcement layers and also settlement under the reinforcement bar

Proper Measurement:

- Utilize cements with low heat development
- Low water content
- Biggest possible maximum particle size (e.g. 0–50 rather than 0–32)
- If required, chill the aggregates to have a low initial fresh concrete temperature
- Set the concrete in layers (layer thickness<80cm)
- Restrain the bottom layers to make sure that the entire section is recompacted as soon as the top layer is set
- Start curing by applying thermal insulation methods
- Make sure the proper design and circulation of joints and concreting sections, so that heat can be dissipated and the temperature developments and deviations can be adjusted

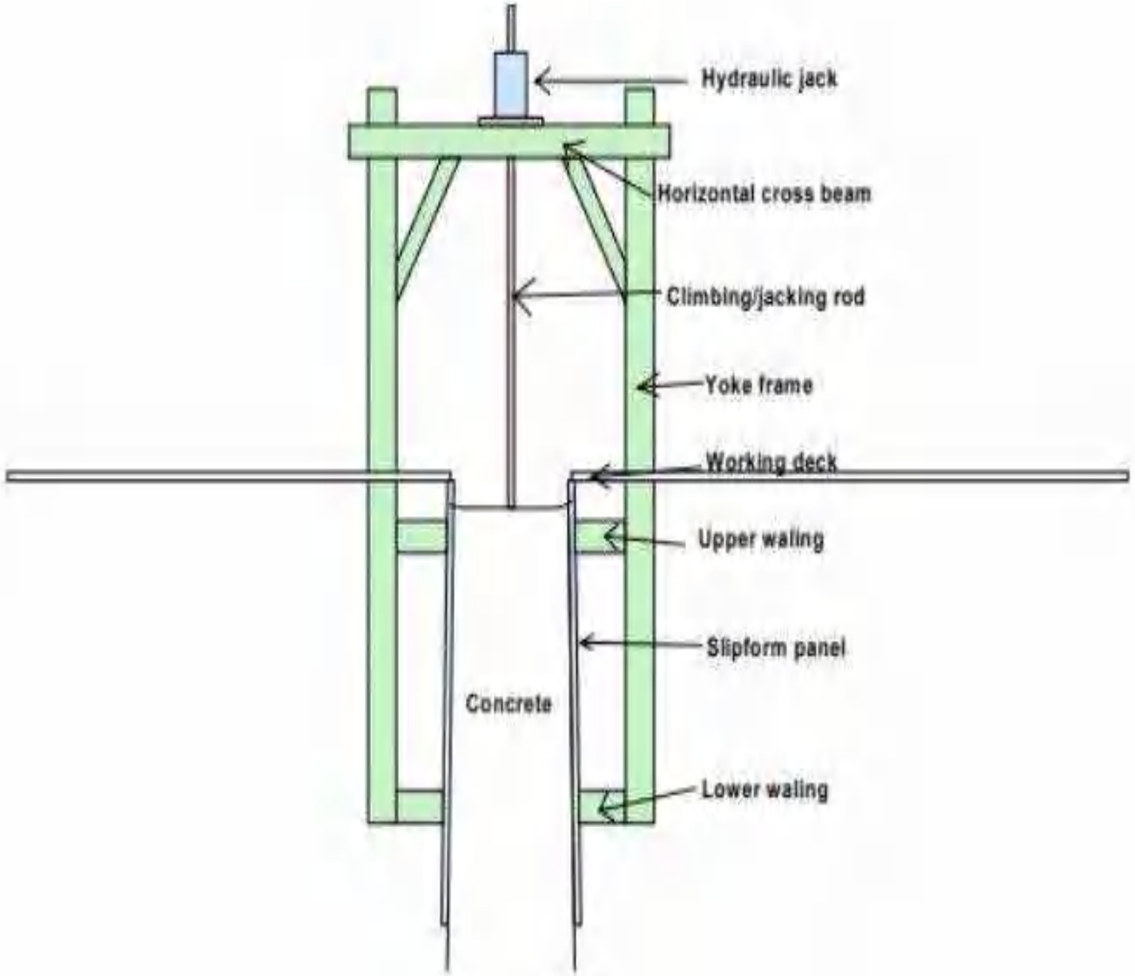
SLIPFORM CONSTRUCTION TECHNIQUE

- Slipform construction technique is an alternative for conventional formwork system which helps in continuous vertical and horizontal construction.
- The slipform helps to conduct continuous pouring of the concrete to the moving formwork.
- The process stops only when the required length of casting is completed.

Development of Slipform Construction Technique

- The property of cement and concrete to gain sufficient strength to stay in shape once cast within the initial setting time of 30 minutes lead to the development of slip form construction technique.
- Engineers took this property to develop a moving formwork system so that the concrete can be poured continuously. The height of the formwork is designed such a way that, during the pouring of the upper level formwork, the concrete poured in the below formwork would have gained initial setting. The concrete exposed when the formwork moves up will remain firm.

Components of Slipform



The slipform system is designed with varied features.

- Generally, it consist of yoke legs.
- Yoke legs are employed to lift and sustain the weight of the entire structure, so that it behaves as a single unit.
- Yoke legs are also used to connect with the beams, scaffoldings and working platforms to serve the supporting purpose.
- To the yoke legs, walk-away brackets are connected.
- These walkway brackets will enable proper placement of the concrete.
- The whole slipform assembly is lifted by means of strand rods and lifting jacks.
- These primary components are located at equal intervals so that the uniform and good distribution of weight is performed.
- In some construction, lifting process are supported by means of hydraulic pump components.

Features of Slipform Construction Technique

- The slipform construction technique is a rapid and a economic construction method compared to the conventional formwork technique.
- This helps to achieve huge cost saving.
- The technique is best suitable for large building structures and bridges.
- When small structures are concerned, the projects with identical geometry can be easily completed by slipform construction.
- Continuous movement of formwork in upward direction is performed in slip form technique. The movement is facilitated by hydraulic jacks and jack rods.
- In the construction of vertical structures, the rate of rising the formwork upwards will be almost in the rate of 300mm per hour.
- These rise with the help of the supports from other permanent parts of the building.
- The technique of slipform construction will vary based on the type of structure constructed.
- Based on this the frameworks required to support the system will vary.

Applications of Slip form Construction

1. Construction of Regular core high rise structures

The slipform construction technique used in high rise building construction will be performed by vertically extruding the reinforced concrete section. Regular shaped core structures and buildings are easily constructed by this method.

2. Slipform Technique for Chimney Construction

The slipform technique used for the construction of large chimneys, cooling towers and piers are called as tapered slipform. This technique is used for constructing vertical structures with varying wall thickness, or shapes or diameters.

3. Construction of Steel Tanks

Slipform construction technique helps to construct the large volume cisterns in industries and factories in a cost effective way.

4. Construction of Water Towers

The slipform technique helps to construct the walls of water tanks uniformly with better quality. Tanks of thousands of litres are easily constructed by this method.

Advantages of Slipform Construction Technique

- Non-stop Method of Construction
- Increase rate of construction
- Increase the productivity
- Provide more working space
- Creates safe work environment for the workers
- Employs less accessory equipment
- Increase flexibility in construction
- Reduced Labor costs
- Scaffolding and temporary works in construction is reduced
- Uniform wall sections and layouts are obtained

Disadvantages of Slipform Construction Technique

- High –cost for initial setup
- Requires Specialized workers and expertise
- Need sophisticated Equipment
- Dimensional Accuracy can go low in certain conditions

PREFABRICATION TECHNOLOGY

- Prefabrication is the practice of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located.
- The term is used to distinguish this process from the more conventional construction practice of transporting the basic materials to the construction site where all assembly is carried out.
- The term prefabrication also applies to the manufacturing of things other than structures at a fixed site.
- It is frequently used when fabrication of a section of a machine or any movable structure is shifted from the main manufacturing site to another location, and the section is supplied assembled and ready to fit.
- It is not generally used to refer to electrical or electronic components of a machine, or mechanical parts such as pumps, gearboxes and compressors which are usually supplied as separate items, but to sections of the body of the machine which in the past were fabricated with the whole machine.
- Prefabricated parts of the body of the machine may be called 'sub-assemblies' to distinguish them from the other components.

Process and theory

- An example from house-building illustrates the process of prefabrication.
- The conventional method of building a house is to transport bricks, timber, cement, sand, steel and construction aggregate etc. to the site, and to construct the house on site from these materials.
- In prefabricated construction, only the foundations are constructed in this way, while sections of walls, floors and roof are prefabricated (assembled) in a factory (possibly with window and door frames included), transported to the site, lifted into place by a crane and bolted together.
- The theory behind the method is that time and cost is saved if similar construction tasks can be grouped, and assembly line techniques can be employed in prefabrication at a location where skilled labour is available, while congestion at the assembly site, which wastes time, can be reduced.

Advantages

- Moving partial assemblies from a factory often costs less than moving pre-production resources to each site
- Deploying resources on-site can add costs; prefabricating assemblies can save costs by reducing on-site work
- Factory tools - jigs, cranes, conveyors, etc. - can make production faster and more precise
- Factory tools - shake tables, hydraulic testers, etc. - can offer added quality assurance
- Consistent indoor environments of factories eliminate most impacts of weather on production

Disadvantages

- Transportation costs may be higher for voluminous prefabricated sections than for their constituent materials, which can often be packed more densely.
- Large prefabricated sections may require heavy-duty cranes and precision measurement and handling to place in position

Benefits of Prefabricated Construction

- Eco-Friendly
- Financial Savings
- Flexibility
- Consistent Quality
- Reduced Site Disruption
- Shorter Construction Time
- Safety


THANK YOU

MODULE 5

DURABILITY OF CONCRETE

- **Concrete** was considered to be very **durable** material requiring a little or no maintenance, except when it is subjected to highly aggressive environments.
- Compressive strength is a measure of durability to a great extent, but, it is not entirely true that the strong concrete is always a durable concrete.
- It is now recognized that strength of concrete alone is not sufficient for the measurement of durability of concrete, the **degree of harshness of the environmental condition** to which concrete is exposed over its entire life is equally important.
- Therefore, both **strength and durability** have to be considered explicitly at the design stage.

Definition of Durability

- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

Factors Affecting Durability of Concrete

1. Exposure Conditons

- **Mild:** Concrete surfaces protected against weather or aggressive conditions, except those in coastal area
- **Moderate:** Concrete surfaces sheltered from severe rain or freezing. Concrete exposed to condensation and rain. Concrete continuously underwater.

- **Aggressive:** concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing wet or severe condensation.
- **Severe:** concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions.
- **Extreme:** Surface of members in tidal zone , members in direct contact with liquid / solid aggressive chemicals

2. Cement Content

- Mix must be designed to ensure cohesion and prevent segregation and bleeding.
- If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction.
- However, if water is added to improve workability, w/c ratio increases leading to highly permeable material.

3. Compaction

- The concrete as a whole contain voids by inadequate compaction.
- It is governed by the compaction equipments used, type of formwork and density of steel.

4. Curing

- It is very important to permit strength development and to ensure hydration process completely.

5. Cover

- The thickness of concrete cover must follow the limits set in codes.

6. Water-Cement Ratio

- For durable concrete, use of w/c ratio is the fundamental requirement to produce dense and impermeable concrete.
- Low w/c ratio concrete are less sensitive to carbonation and external chemical attack.
- Less chance of corrosion of unprotected steel in concrete with low w/c ratio.

7. Permeability.

- Higher permeability is caused by higher porosity.
- Therefore, proper curing, sufficient cement, proper compaction and suitable concrete cover should be provided.

Types of Durability

1. Physical Durability
2. Chemical Durabilty

Durability Problems in Concrete

1. Reinforcement corrosion
2. Fire Resistance
3. Frost Damage
4. Sulphate Attack
5. Alkali Silica reaction
6. Concrete in sea water

1. Corrosion Of Steel

- Corrosion of steel in concrete is an electrochemical process.
- When there is a difference in electrical potential along the steel reinforcement in concrete, an **electrochemical cell is set up**.
- In the steel, one part becomes anode and other part becomes cathode connected by electrolyte in the form of pore water in the hardened cement paste.
- The positively charged ferrous ions Fe^{++} at the anode pass into solution while the negatively charged free electrons e^{-} pass through the steel into cathode where they are absorbed by the constituents of the electrolyte and combine with water and oxygen to form **hydroxyl ions** $(OH)^{-}$.
- These travel through the electrolyte and combine with the ferrous ions to form **ferric hydroxide** which is converted by further oxidation to **rust**.

Anodic reactions

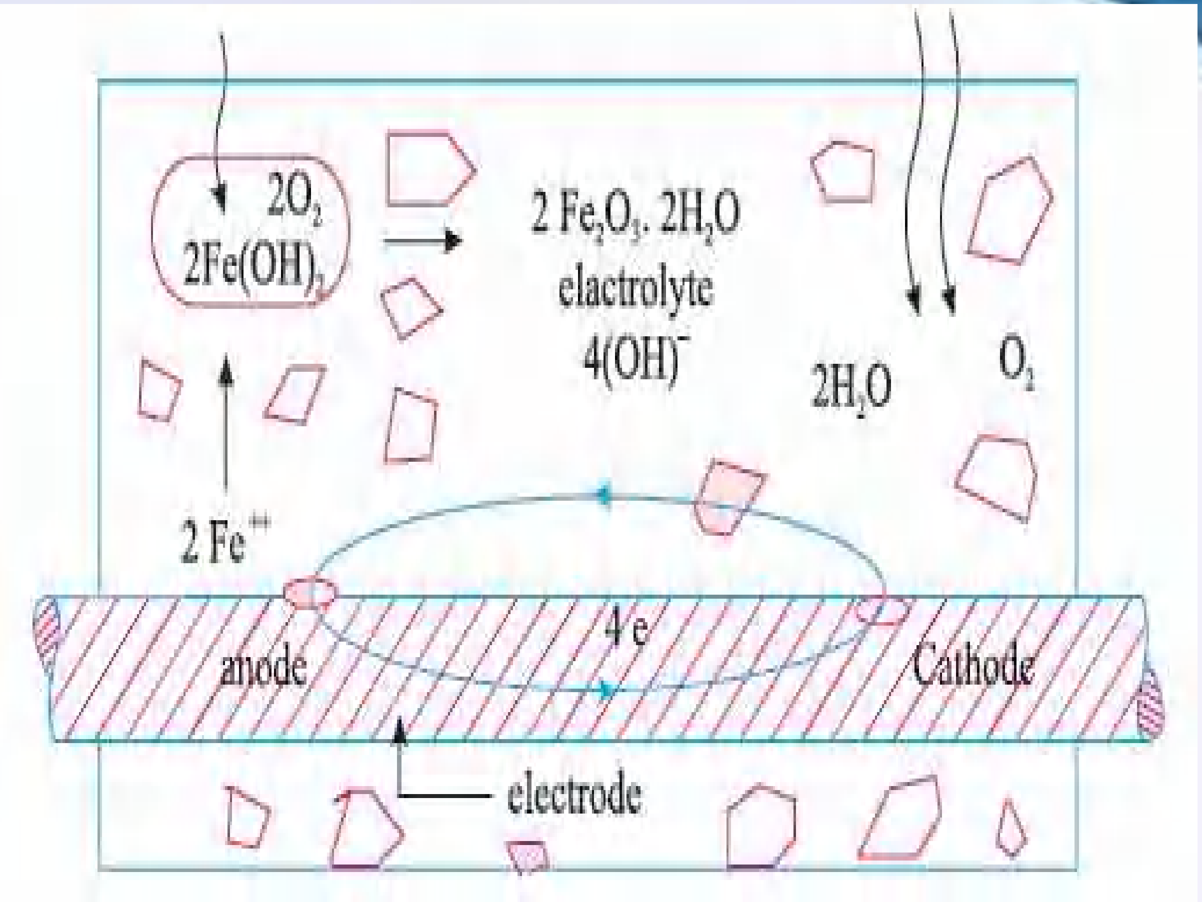
$Fe \longrightarrow Fe^{++} + 2e^-$

$Fe^{++} + 2(OH)^- \longrightarrow Fe(OH)_2$ (Ferrous hydroxide)

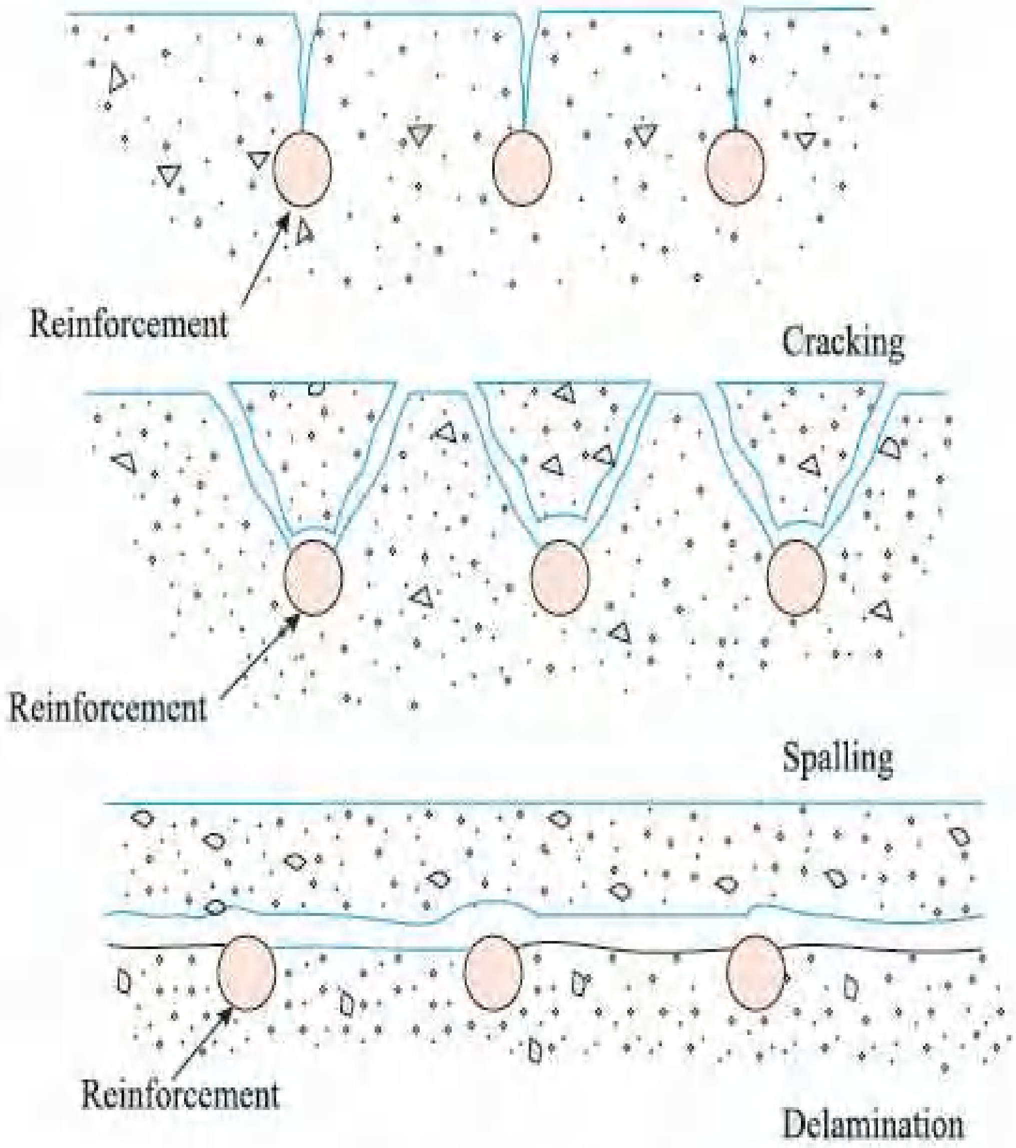
$4\ Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3$ (Ferric oxide)

Cathodic reaction

$4e^- + O_2 + H_2O \longrightarrow 4(OH)^-$



- **No corrosion takes place** if the concrete is dry or probably below relative humidity because enough water is not there to promote corrosion. It can also be noted that corrosion does not take place if concrete is fully immersed in water because diffusion of oxygen does not take place into the concrete.
- The products of corrosion occupy a volume as many as **six times** the original volume of steel depending upon the oxidation state.
- The increased volume of rust exerts thrust on cover concrete resulting in cracks, spalling or delamination of concrete.



Diagrammatic representation of damage induced by corrosion cracking spalling, and delamination

Corrosion Control

Measures to control the reinforcement corrosion are:

- **Metallurgical methods** – Altering structure by metallurgical process - Rapid quenching of hot bars by series of water jets or by keeping hot steel bars for a short time in water bath.
- **Corrosion inhibitors** – Chemicals such as nitrites, phosphates etc
- **Coatings to reinforcement -** Durable barrier against chlorides – cheapest : cement slurry
- **Cathodic protection** – An external DC electric power is used to provide sufficient current. Makes the metal surface cathode of an electrochemical cell. Connects the metal to be protected to a more easily corroded sacrificial metal to act as anode. The sacrificial metal corrodes instead of protected metal.
- **Coatings to concrete -** Surface coatings for protection and decoration
- **Design and detailing –** Spacing between bars , proper cover to reinforcements etc

2.Fire Resistance

- Concrete, though not a refractory material is incombustible and has good fire-resistant properties. Fire resistance of concrete structure is determined by **three main factors** -
  - The capacity of the concrete itself to withstand heat without losing strength, without cracking or spalling;
  - The conductivity of the concrete to heat, and
  - Coefficient of thermal expansion of concrete.
- For reinforced concrete, the fire resistance is not only dependent upon the type of concrete but also on the **thickness of cover to reinforcement**.
- The fire introduces high temperature gradients and as a result of it, the surface layers tend to separate and spall off from the cooler interior.

- Hydrated hardened concrete contains a considerable proportion of free calcium hydroxide which loses its water above 400°C leaving calcium oxide. If this calcium oxide is exposed to moist air, rehydrates to calcium hydroxide accompanied by an expansion in volume. This expansion disrupts the concrete. Portland blast furnace slag cement is found to be more resistant to the action of fire in this regard.
- In mortar and concrete, the aggregates undergo a **progressive expansion on heating** while the hydrated products of the set cement, **beyond the point of maximum expansion, shrinks**. These two opposing actions progressively weaken and crack the concrete.

- The various aggregates used differ considerably in their behaviour on heating:
- **Quartz**, the principal mineral in sand, granites and gravels expands steadily upto about 573°C. At this temperature it undergoes a sudden expansion of 0.85%. This expansion has a disruptive action on the stability of concrete. The fire resisting properties of concrete is least, if quartz is the predominant mineral in the aggregate.
- Limestone expands steadily until temperature of about 900°C and then begins to contract. Since it takes place only at a very high temperature of 900°C, it has been found that dense limestone is considered as a good fire resistant aggregate.
- The best fire resistant aggregates, amongst the igneous rocks are, the **basalts and dolomites**.
- Broken bricks also form a good aggregate in respect of fire resistance.

- The long series of tests indicated that even the **best fire resistant concretes have been found to fall if concrete is exposed for a considerable period to a temperature exceeding 900°C, while serious reduction in strength occurs at a temperature of about 600°C. Concrete does not show appreciable loss of strength up to a temperature of about 300°C. The loss of strength may be about 50% or more at about 500°C.**

3. Frost Damage

- The lack of durability of concrete on account of freezing and thawing action of frost is not of great importance to Indian conditions.
- But it is of greatest considerations in most part of the world.
- However, certain regions in India, experience sub-zero temperatures in winter.
- The concrete structures particularly, the one which are exposed to atmosphere are subjected to cycles of freezing and thawing and as such suffer from the damaging action of frost.
- The frost action is one of the most powerful weathering action on the durability of concrete.
- In the extreme conditions, the life span of concrete can be reduced to just a couple of years.

- Fresh concrete should not be subjected to freezing temperature.
- Fresh concrete contains a considerable quantity of free water; if this free water is subjected to freezing temperature discrete ice lenses are formed.
- Water expands about 9% in volume during freezing. The formation of ice lenses formed in the body of fresh concrete disrupt the fresh concrete causing nearly permanent damage to concrete. The fresh concrete once subjected to forst action, will not recover the structural integrity.
- The hardening concrete also should not be subjected to an extremely low temperature.
- It has been estimated that the freezing of water in the hardened concrete may exert a pressure of about 14 MPa.
- The fully hardened concrete is also vulnerable to forst damage, particularly to the effect of alternate cycles of freezing and thawing.

THEORIES OF DAMAGE

- One of the theories attributes the damage directly to the empty space available being insufficient to accommodate the additional solid produced when the free water held in concrete freezes.
- Another theory attributes the failure to the production of pressure due to the growth of ice lenses parallel to the surface of the concrete owing to the migration of water from capillaries.
- Another theory explains the failure to generation of water pressure within the capillary cavities as the ice crystals grow.

ASSESSMENT OF FROST DAMAGE

- The frost damage can be assessed in several ways.

1. Assessment of loss of weight of a sample of concrete subjected to a certain number of cycles of freezing and thawing.
2. Measuring the change in the ultrasonic pulse-velocity.
3. The resistance of the concrete to freezing and thawing is also measured by the durability factor.

4. Sulphate Attack

- The term sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates.
- Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water.
- Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products.
- Of all the sulphates, **magnesium sulphate** causes maximum damage to concrete. A characteristic **whitish appearance** is the indication of sulphate attack.
- Magnesium sulphate has a more far reaching action than other sulphates because it reacts not only with calcium hydroxide and hydrated calcium aluminates like other sulphates but also decomposes the hydrated calcium silicates completely and makes it a **friable mass**.

- The **rate of sulphate attack** increases with :
- ❖ The increase in the strength of solution ie., a saturated solution of magnesium sulphate can cause serious damage to concrete with higher w/c ratio in a short time.
- ❖ The speed in which the sulphate gone into the reaction. When the concrete is subjected to the pressure of sulphate bearing water on one side the rate of attack is highest.

Methods of Controlling Sulphate Attack

(a) Use of Sulphate Resisting Cement

(b) Quality Concrete

(c) Use of air-entrainment

(d) Use of pozzolana

(e) High Pressure Steam Curing

(f) Use of High Alumina Cement

(a) Use of Sulphate Resisting Cement

- The most efficient method of resisting the sulphate attack is to use cement with the low C_3A (7%) content.

(b) Quality Concrete

- A well designed, placed and compacted concrete which is dense and impermeable exhibits a higher resistance to sulphate attack. Similarly a concrete with low w/c ratio also demonstrates a higher resistance to sulphate attack.

(c) Use of air-entrainment

- Use of air-entrainment to the extent of about **6%** has beneficial effect on the sulphate resisting qualities of concrete.

(d) Use of pozzolana

- Incorporation of or replacing a part of cement by a pozzolanic material reduces the sulphate attack.

(e) High Pressure Steam Curing

- High pressure steam curing improves the resistance of concrete to sulphate attack.

(f) Use at High Alumina Cement

- High alumina cement contains no calcium hydroxide in the set cement, in contrast to Portland cement.

5. Alkali Silica Reaction

- Some of the aggregates contain reactive silica, which reacts with alkalis or hydroxyl ions in pore water and cement.
- The reaction produces alkali-silica gel. It is of unlimited swelling type under favorable conditions of moisture and temperature in voids and cracks.
- It causes disruption and pattern cracking.

Factors Promoting the Alkali-Silica Reaction

(i) Reactive type of aggregate

(ii) High alkali content in cement;

(iii) Availability of moisture;

(iv) Optimum temperature conditions---

The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C.

(v) The grain size of aggregates

(vi) The exposure condition

(vii) The alkali calcium concentration in the pore water

Control of Alkali-Silica Reaction

(i) Selection of non-reactive aggregates;

(ii) By the use of low alkali cement;

(iii) By the use of corrective admixtures such as pozzolanas;

(iv) By controlling moisture condition and temperature.

6.Concrete In Sea Water

- The concrete in sea water is subjected to chloride induced corrosion of steel, freezing and thawing, salt weathering, abrasion by sand held in water and other floating bodies.
- Magnesium sulphate in sea water reacts with free calcium hydroxide in set Portland cement to form calcium sulphate, at the same time precipitating magnesium hydroxide.
- $MgSO_4$ also reacts with the hydrated calcium aluminate to form calcium sulpho aluminate.
- These have often been assumed to be the actions primarily responsible for the chemical attack of concrete by sea water.

- It is commonly observed that deterioration of concrete in sea water is often not characterised by the expansion found in concrete exposed to sulphate action, but takes more the form of erosion or loss of constituents (leaching).
- The most severe attack of sea water on concrete occurs just above the **level of high water**. The portion between low and high water marks is less affected and the parts below the water level which are continuously remain immersed are least affected. The crystallization of salt in the portion of concrete above high water level is responsible for disruption of concrete.
- In place of cold climatic region, the freezing of water in pores at the spray level of concrete is responsible for causing lack of durability in concrete.

- It is to be admitted that concrete is not l00% impervious.

  The water that permeates into the concrete causes corrosion of steel.

- Sea water holds certain quantity of sand and silt particularly in the shallow end. The velocity of wave action causes abrasion of concrete. The impact and the mechanical force of wave action also contribute to the lack of durability of concrete.

Steps to improve the durability of concrete in sea water

1. Use of cement with low C_3A content

2. Use of rich concrete with low w/c ratio

3. Provide adequate cover

4. Use of pozzolanic material

5. A good compaction, well-made construction joints etc. are other points helping the durability of concrete in sea water.

6. Use high pressure steam-cured prefabricated concrete elements

Quality Control Of Concrete

- Concrete is generally produced in batches at the site with the locally available materials of variable characteristics. It is, therefore, likely to vary from one batch to another.
- The magnitude of this variation depends upon several factors such as **variation in the quality of constituent materials**; **variation in mix proportions due to batching process; variation in the quality of batching and mixing equipment available; the quality of overall workmanship and supervision at the site.**

- Moreover, concrete undergoes a number of operations, such as transportation, placing, compacting and curing. During these operations considerable variations occur partly due to **quality of plant available and partly due to differences in the efficiency of techniques used**.
- Therefore, the aim of quality control is to reduce the above variations and produce uniform material providing the characteristics desirable for the work.
- Quality control is conformity to the specification more or less.
- The most practical method of effective quality control is to **check what is done in totality to conform to the specifications**.

FACTORS CAUSING VARIATIONS IN THE QUALITY OF CONCRETE

PERSONNEL

- The basic requirement for the success of any quality control plan is the availability of experienced, knowledgeable and trained personnel at all levels. The designer and the specification-writer should have the knowledge of construction operations as well. The site engineer should be able to comprehend the specification stipulations.

MATERIAL, EQUIPMENT AND WORKMANSHIP

- For uniform quality of concrete, the ingredients (particularly the **cement**) should preferably be used from a single source. When ingredients from different sources are used, the strength and other characteristics of the materials are likely to change and, therefore, they should only be used after proper evaluation and testing.

- **Grading, maximum size, shape, and moisture content of the aggregate** are the major meet of variability. Aggregate should be separately stock piled in single sizes.
- The aggregate should be free from impurities and deleterious materials; since for every 1 per cent of clay in sand, there could be as much as 5 per cent reduction in the strength of the concrete.
- The moisture content of aggregates should be taken into account while arriving at the quantity of mixing water. Bulking of sand is important in several ways.
- The **water** used for mixing concrete should be free from silt, organic matter, alkali and suspended impurities. Sulphates and chlorides in water should not exceed the permissible limits. Generally, water fit for drinking may be urged for mixing concrete.

- The **equipment** used for batching, mixing and vibration should be of the right capacity. Mixer's performance should be checked for conformity to the requirements of the relevant standards. Concrete should be mixed for the required time, both under mixing and over mixing should be avoided. The vibrators should have the required frequency and amplitude of vibration.
- The **green concrete** should be handled, transported and placed in such a manner that it does not get segregated. The time interval between mixing and placing the concrete should be reduced to the minimum possible. Anticipated targets of strength, impermeability and durability of concrete can be achieved only by thorough and adequate compaction. One per cent of the air voids left in concrete due to incomplete compaction can lower the compressive strength by nearly 5 per cent.
- **Adequate curing** is essential for handling and development of strength of concrete.

Field Control

- The field control, i.e. **inspection and testing**, play a vital role in the overall quality control plan. Inspection could be of **two types**, quality control inspection and acceptance inspection.
- Apart from the tests on concrete materials, concrete can be tested both in the fresh and hardened stages. Of these two, the tests on fresh concrete offer some opportunity for necessary corrective actions to be taken before it is too late.
- These include test on workability, unit weight or air content (where air-entrained concrete is used), etc.

ADVANTAGES OF QUALITY CONTROL

(i) Quality control means a rational use of the available resources after testing their characteristics and reduction in the materials costs.

(ii) In the absence of quality control there is no guarantee that over-spending in one-area will compensate for the weakness in another, eg., an extra bag of cement will not compensate for incomplete compaction or inadequate curing. Proper control at all the stages is the only guarantee.

(iii) In the absence of quality control at the site, the designer is tempted to overdesign, so as to minimize the risks. This adds to the overall cost.

(iv) Checks at every stage of the production of concrete and rectification of the faults at the right time expedites completion and reduces delay

(v) Quality control reduces the maintenance costs.

Sampling and Acceptance Criteria

Sampling

- A **random sampling procedure** should be adopted to ensure that each concrete batch will have reasonable chance of being tested. It means that sampling and cube casting should be spread over the entire period of concreting. In case of more than one mixing units or batching plants are used for a concrete construction, the sampling should cover all the mixing units.

Frequency of Sampling:

- The minimum frequency of sampling of concrete of each grade will be as shown in Table----

Frequency of Sampling

Quantity of concrete in the work, m^3	*Number of Samples*
1–5	1
6–15	2
16–30	3
31–50	4
51 and above	4 plus one additional sample for each additional 50 m^3 or part thereof

Note: At least one sample must be taken from each shift.

Test Specimen:

- Three test specimens should be made for each sample for testing at 28 days. Additional samples may be required for 7 days strength or for finding out the strength for striking the formwork etc.

Test Results:

- The test result of sample is the average of the strength of three specimen. The individual variation should not be more than ± 15 per cent of the average. If more, the test result of the sample is rejected.
- In a major construction site a register is maintained showing the test results of the samples of concrete taken. Possibly samples should denote the time and part of the structure to which the concrete represented by this samples has been used, so that the strength of test specimen and the part of the structure can be matched, if need be. The test register is an important legal document and should be kept in safe custody.

- When the number of samples tested becomes more than 30 or at a predetermined interval of time, standard deviation is worked out to see that the mix design adopted is neither very conservative nor too liberal.
- If so, using the standard deviation actually worked out from the kind of quality control exercised at site, a fresh mix design is worked out and the proportions of materials are recast.
- Mix design should be reviewed continuously to make the whole concreting operation safe and economical.

Standard deviation:

- This is the root mean square deviation of all the results. This is denoted by **s or σ**.
- Numerically it can be explained as,

$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$$

σ = Standard deviation,
n = number of observations
x = particular value of observations
$\bar{x}$ = arithmetic mean.

From IS 456-2000, Table 8 Assumed Standard Deviation

Grade of Concrete	Assumed Standard Deviation N/mm²
M 10 M 15	3.5
M 20 M 25	4.0
M 30 M 35 M 40 M 45 M 50	5.0

Acceptance Criteria

- Acceptance Sampling: It is the process of evaluating portion of product material in a lot for the purpose of accepting or rejecting the lot as either conforming or non conforming to quality specifications.

Compressive strength

The concrete is deemed to comply with the compressive strength requirements when both the following conditions are met :---

(a) The mean strength determined from any group of four consecutive test results complies with the appropriate limits in column 2 of Table.

(b) Any individual test result complies with the appropriate limits in column 3 of Table.

Characteristic Compressive Strength Compliance Requirements as per IS 456-2000

Specified Grade	Mean of the Group of 4 Non-over-lapping Consecutive Test Results in N/mm^2	Individual Test Results in N/mm^2
(1)	(2)	(3)
M 15	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2 whichever is greater	$\geq f_{ck}$ − 3 N/mm^2
M 20 or above	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 4 N/mm^2 whichever is greater	$\geq f_{ck}$ − 4 N/mm^2

Flexural strength

- When both the following conditions are met, the concrete complies with the specified flexural strength.
  - (a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm^2 .
  - (b) The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm^2 .
- In case the test results show unacceptable values, the compressive strength can be established from core test and load test.

Core Test

- The number of test cores will be not less than three which should represent the whole of the doubtful concrete.

- The core strength should be converted to equivalent cube strength. If the equivalent Cube strength gives at least 85 per cent of characteristic strength of the grade of concrete, and no individual core has a strength less than 75 per cent, the strength of the concrete can be considered adequate.
- In case the core test results do not satisfy the requirements or where such core tests have not been done, load test may be resorted to.

Load Tests for Flexural Member

- The structure should be subjected to a load equal to full load plus 1.25 times the live load for a period of 24 hours and then the imposed load is removed.
- The deflection due to imposed load only is recorded. If within 24 hours of removal of the imposed load, the structure does not recover at least 75 per cent of the deflection under super imposed load, the test may be repeated after a lapse of 72 hours. If the recovery is less than 80 percent, the structure is deemed to be unacceptable.

NON- DESTRUCTIVE TESTING OF CONCRETE

- There are a number of non-destructive tests and testing techniques that are being used to evaluate concrete.

REBOUND HAMMER TEST

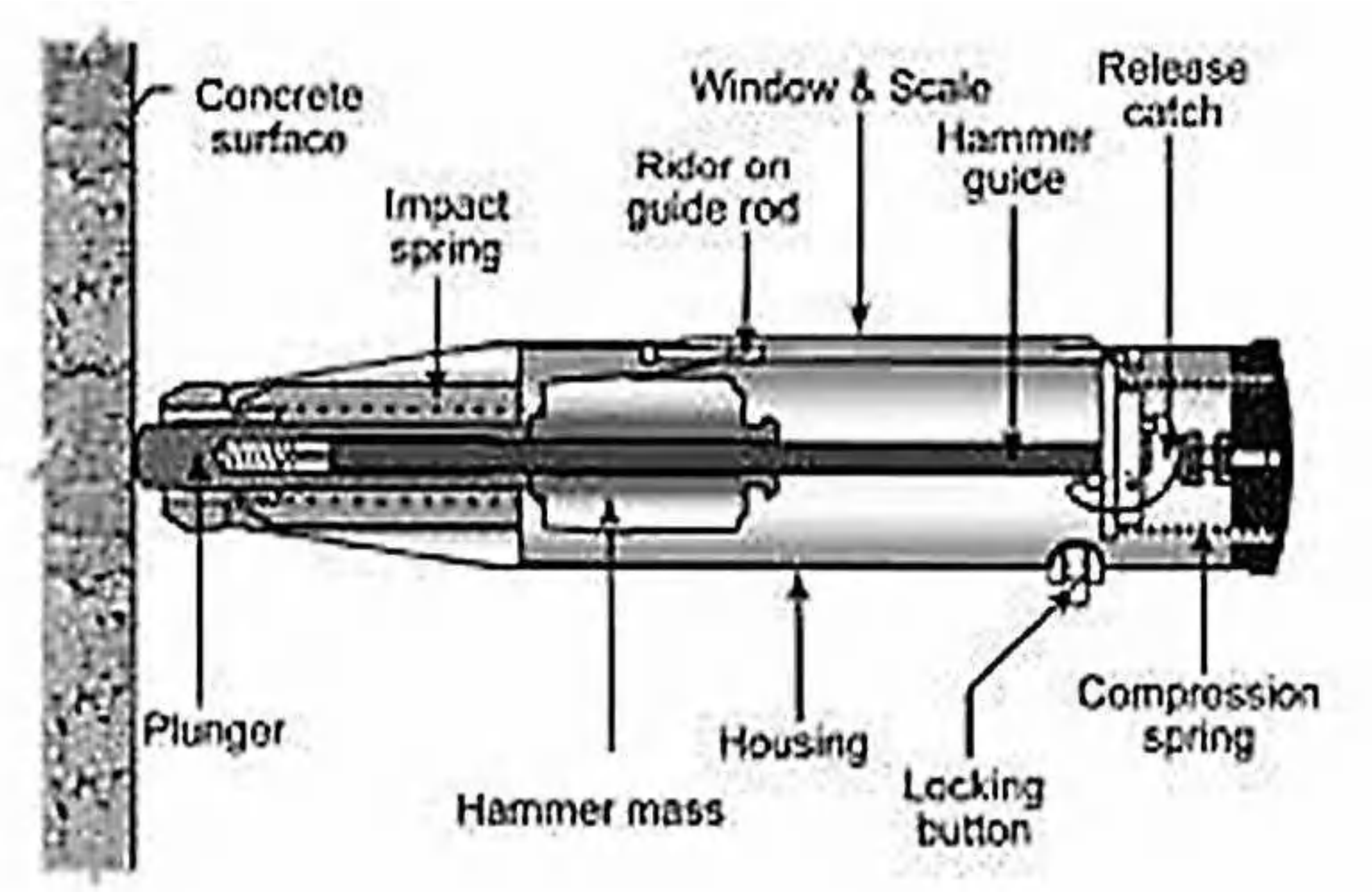
INTRODUCTION

- Non Destructive Testing are non invasive techniques to determine the integrity of a material, component or structure or measure some characteristic of an object
- It is an assessment without harming or destroying the specimen
- Rebound Hammer Test is one of the Non Destructive test which is used to determine compressive strength of concrete

REBOUND HAMMER TEST

- ❖Rebound hammer is principally a surface hardness tester and was developed in 1948
- ❖Rebound hammer is designed to carry out the instant non- destructive test on concrete structures without damage and gives an immediate indication of compressive strength of concrete using a calibration curve

- A rebound hammer has the following parts:
    1. Impact Spring
    2. Rider on Guide Rod
    3. Window and Scale
    4. Hammer Guide
    5. Release Catch
    6. Compressive Spring
    7. Locking Button
    8. Housing
    9. Hammer mass
    10. Plunger

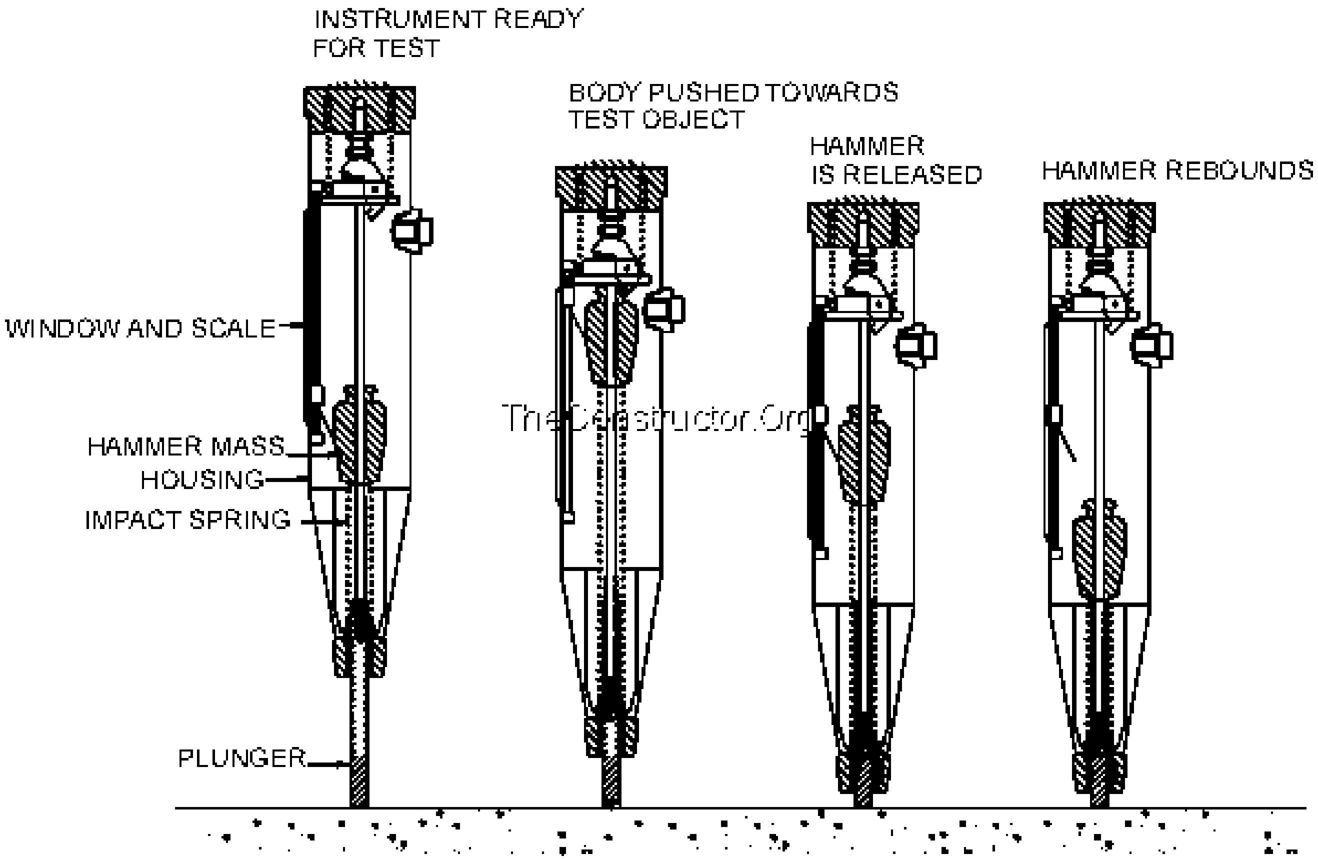


Parts of Rebound Hammer

PRINCIPLE

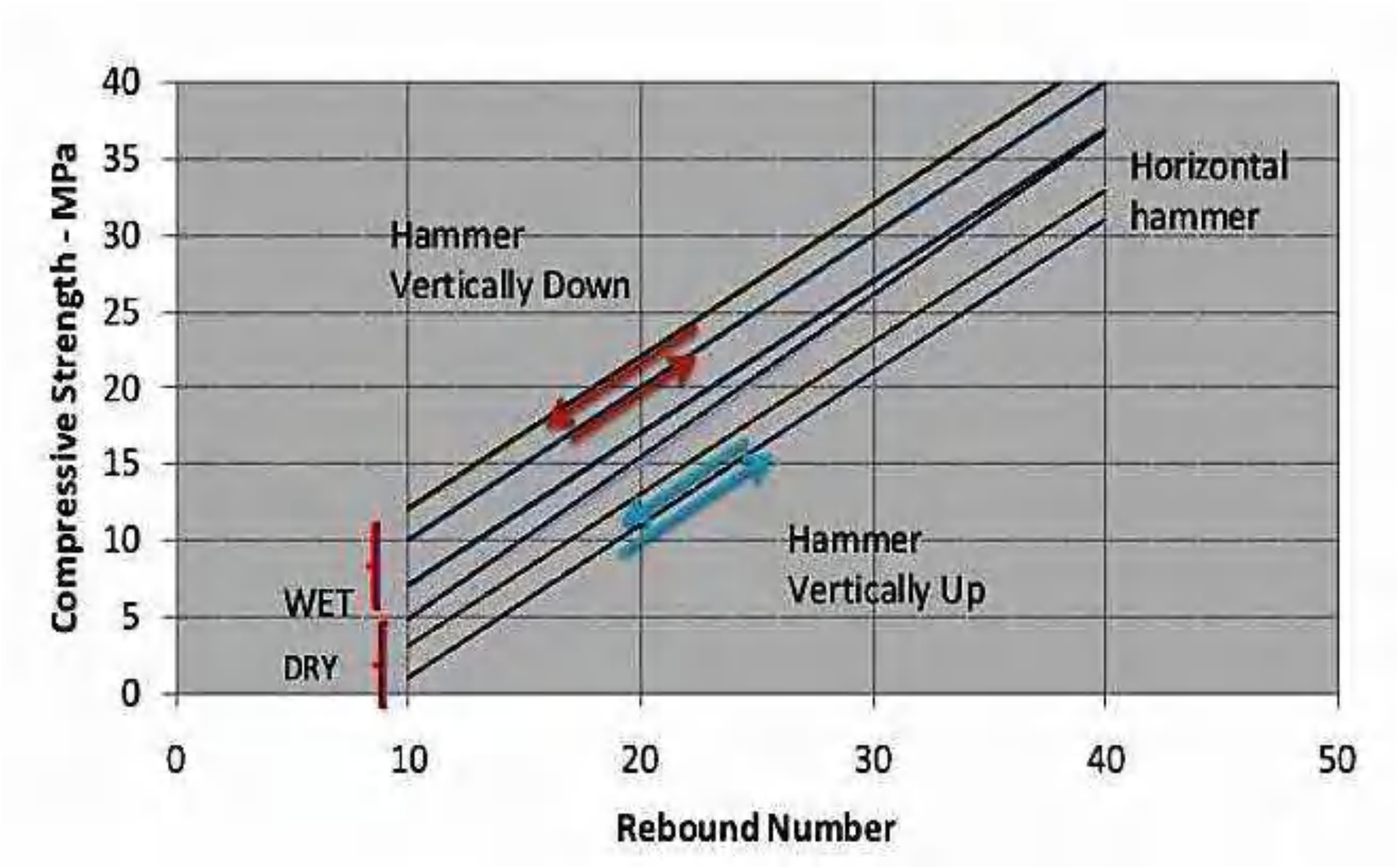
- It consists of a spring control hammer that slides on a plunger within a tubular housing.
- When the plunger of rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete

- ❖The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete
- ❖The rebound is read off along a graduated scale and is designated as the rebound number or rebound index
- ❖The test can be conducted horizontally or vertically



Rebound Hammer Test Process

- From the rebound number obtained, we can find out the compressive strength of concrete by using a calibration chart
- It shows the value of compressive strength when the hammer is plunged horizontally or vertically



Compressive Strength - MPa
40
35
30
25
20
15
10
5
0
Hammer
Vertically Down
Horizontal
hammer
Hammer
Vertically Up
WET
DRY
0
10
20
30
40
50
Rebound Number

❖ The quality of concrete can be determined using rebound number from the table below:

Average Rebound Number	Quality of Concrete
>40	Very Good Hard Layer
30-40	Good Layer
20-30	Fair
<20	Poor Concrete

ADVANTAGES

- Simple to use
- No special experience is needed to conduct the test
- Large number of measurements can be taken rapidly
- Establishes uniformity of properties
- Equipment is inexpensive and is readily available

DISADVANTAGES

- Evaluates only at the local point and the layer of masonry to which it is applied
- No direct relationship with strength or deformation properties
- Unreliable for the detection of flaws
- Cleaning mechanism is difficult
- The results obtained is affected by smoothness of surface size, shape and rigidity, age of the specimen etc.

APPLICATIONS

- Determining the compressive strength of concrete
- Determining the uniformity of concrete
- Determining the quality of the concrete

Windsor probe test

WINDSOR PROBE TEST

- Windsor probe test is also called penetration resistance test
- Windsor probe is a penetration resisting equipment
- It consist of a gun powder actuated driver ,loaded cartridges, a depth gauge and other accessories

PRNCIPLE

- Under standard conditions the penetration depth is inversely proportional to the compressive strength of concrete but the relation depends on the hardness of the aggregate

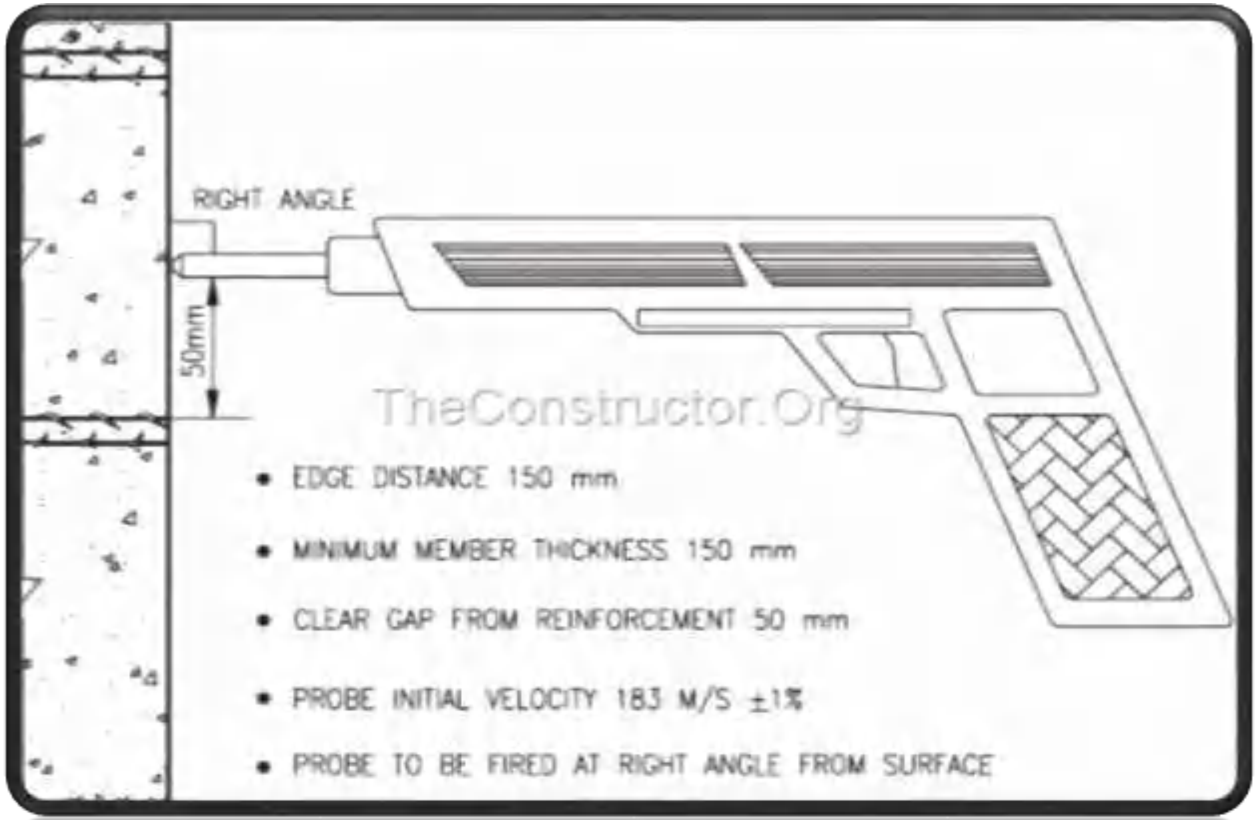
EQUIPMENTS

- The Windsor probe consists of a powder-actuated gun or driver, hardened alloy steel probes, loaded cartridges, a depth gauge for measuring the penetration of probes, and other related equipment.
- As the device looks like a firearm it may be necessary to obtain official approval for its use in some countries.
- The probes have a tip diameter of 6.3 mm, a length of 79.5 mm, and a conical point
- Probes of 7.9 mm diameter are also available for the testing of concrete made with lightweight aggregates.
- The rear of the probe is threaded and screws into a probe driving head, which is 12.7 mm in diameter and fits snugly into the bore of the driver

PROCEDURE

- The area to be tested must have a brush finish or a smooth surface
- To test structures with coarse finishes, the surface first must be ground smooth in the area of the test
- powder-actuated driver is used to drive a probe into the concrete
- If flat surfaces are to be tested a suitable locating template to provide 178 mm equilateral triangular pattern is used, and three probes are driven into the concrete, one at each corner
- A depth gauge measures the exposed lengths of the individual probes
- The mechanical averaging device is used for measuring the average exposed length of the three probes fired in a triangular pattern. The mechanical averaging device consists of two triangular plates
- The reference plate with three legs slips over the three probes and rests on the surface of the concrete. The other triangular plate rests against the tops of the three probes

- The distance between the two plates, giving the mechanical average of exposed lengths of the three probes, is measured by a depth gauge inserted through a hole in the centre of the top plate
- For testing structures with curved surfaces, three probes are driven individually using the single probe locating template. In either case, the measured average value of exposed probe length may then be used to estimate the compressive strength of concrete by means of appropriate correlation data
- The manufacturer of the Windsor probe test system has published tables relating the exposed length of the probe with the compressive strength of the concrete
- For each exposed length value, different values for compressive strength are given, depending on the hardness of the aggregate as measured by the Mohs' scale of hardness
- The tables provided by the manufacturer are based on empirical relationships established in his laboratory. Although the penetration resistance technique has been standardized the standard does not provide a procedure for developing a correlation


RIGHT ANGLE
50mm
TheConstructor.Org
• EDGE DISTANCE 150 mm
• MINIMUM MEMBER THICKNESS 150 mm
• CLEAR GAP FROM REINFORCEMENT 50 mm
• PROBE INITIAL VELOCITY 183 M/S ±1%
• PROBE TO BE FIRED AT RIGHT ANGLE FROM SURFACE

ADVANTAGES AND DISADVANTAGES

- Equipment's are simple and durable
- Requires less maintenance
- Can be used easily with least training given to the nspectors
- Can be used in regions where access to the point of investgation is poor

LIMITATION

- Measures surface and subsurface hardness hence it doesnot give reliable results for strength values
- Type of aggregate affects penetration depth thus it Is necessary to form separate calibration charts
- Damages structure by leaving holes of dia of 8 mm causing minor cracks

APPLICATION

- Test cab be used to assess the uniformity and quality of concrete as the physical difference in concrete will affect the penetration depth
- An area of poor concrete can be described using a series of penetration tests made at regular spaced locations
- Determination of relative concrete strength in the same structure or in different structures without extensive calibration

ULTRA SONIC PULSE VELOCITY

ULTRA SONIC PULSE VELOCITY (UPV TEST)

- An ultrasonic pulse velocity test is an in-situ, non-destructive test to check the quality of concrete and natural rocks.
- In this test, the strength and quality of concrete or rock is assessed by measuring the velocity of an ultrasonic pulse passing through concrete structure or natural rock formation.
- This test is conducted by passing a pulse of ultrasonic wave through concrete to be tested and measuring the time taken by pulse to get through the structure.
- Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

Fig 1: Ultra Sonic Pulse Velocity Equipment

With this ultrasonic test on concrete, following can be assessed:

1. Qualitative assessment of strength of concrete, its gradation in different locations of structural members and plotting the same.
2. Any discontinuity in cross section like cracks, cover concrete delamination etc.
3. Depth of surface cracks.
4. The homogeneity of the concrete
5. Changes in the structure of the concrete which occurs with time
6. The quality of one element of concrete in relation to the another

- This test method consists of measuring travel time, T of ultrasonic pulse of 15 to 50 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end.

- With the path length L, (i.e. the distance between the two probes) and time of travel T, the average pulse velocity of wave propagation (V=L/T) is calculated. Higher the elastic modulus, density and integrity of the concrete, higher is the pulse velocity.

- The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested.

Techniques of Measuring Pulse Velocity through Concrete

There are three ways of measuring pulse velocity through concrete. They are:

- ❑Direct transmission.
- ❑ Indirect transmission.
- ❑Surface transmission.

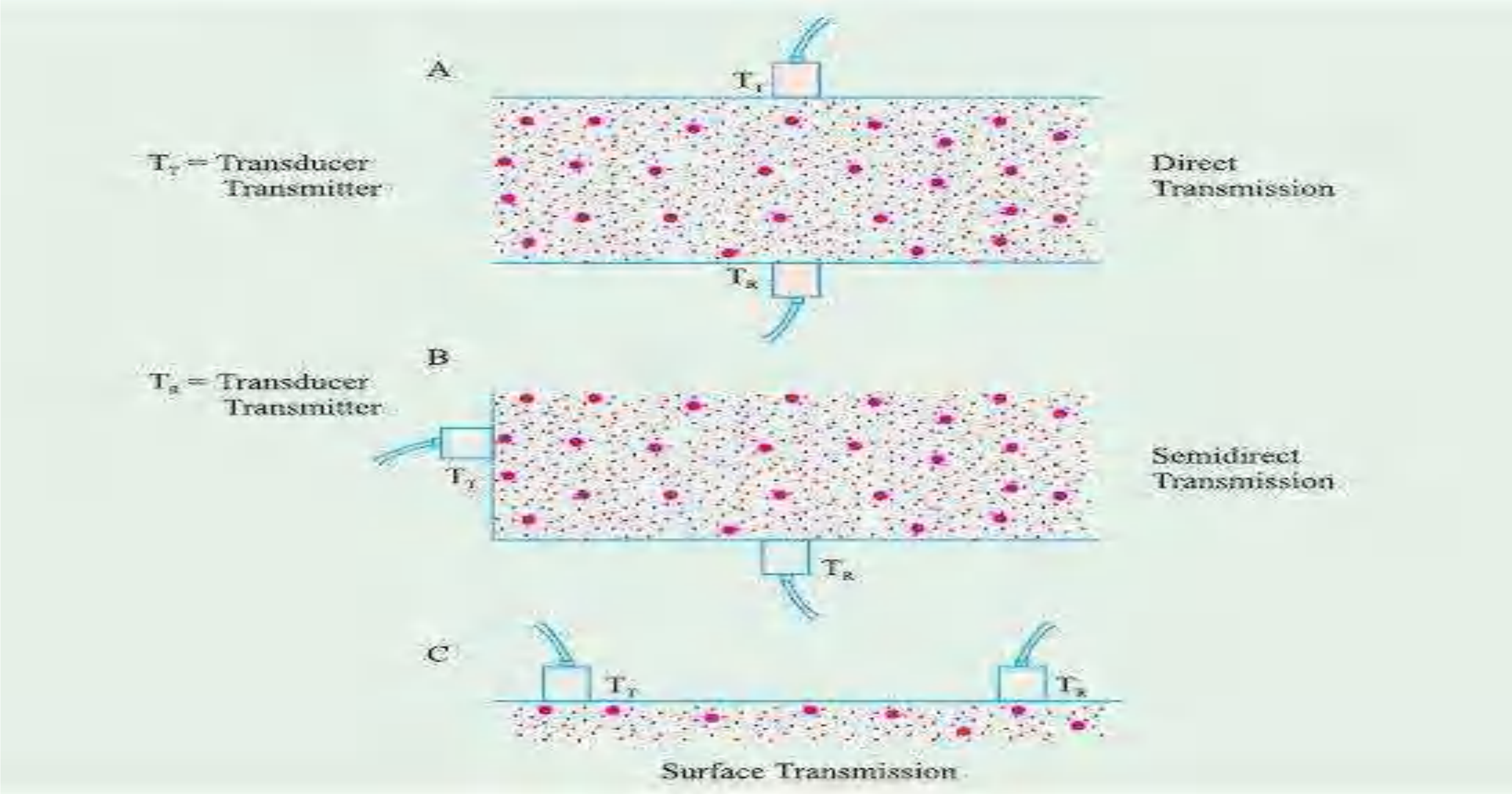


Fig 2: Techniques of Measuring Pulse Velocity

- The direct transmission method is generally preferred since the maximum energy of the pulse is being directed at the receiving transducer and this gives maximum sensitivity.
- The indirect transmission arrangement is the least sensitive and for a given path length, produces a single which has only about 2% or 3% of that produced by direct transmission. This arrangement is used when only one face of the concrete is accessible, when the depth of the surface crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest.
- The semi direct transmission arrangement has a sensitivity intermediate between those of the other two arrangements. In this method, there is uncertainty regarding path length. It is generally found to be sufficient accurate, if the length is measured from centre of transducer faces.

The pulse velocity in concrete may be influenced by:

1. Path length
2. Lateral dimension of the specimen tested
3. Presence of reinforcement steel
4. Moisture content of the concrete
5. Surface condition
6. Temperature of concrete

FACTORS AFFECTING THE MEASUREMENT OF PULSE VELOCITY

1. Smoothness of contact surface under test:

- It is important to maintain good contact between the surface of concrete and the face of each transducer.
- Generally this does not pose any problem because in normal testing sufficient cast surfaces are available for good contact.
- However, when it is necessary to hold the transducer against an unmoulded surface, for example, the top surface of a test cylinder, it is desirable to smoothen the surface by the use of a carborundum stone and the transducers should be held tightly against the concrete surface.
- In addition, the use of a coupling medium such as a thin film of oil, soap, jelly, or kaolin glycerol paste should be used.

2. Influence of path length on pulse velocity:

- As concrete is inherently heterogeneous, it is essential that path length be sufficiently long so as to avoid any errors introduced due to its heterogeneity.
- In field work, this does not pose any difficulty because pulse velocity measurements are generally carried out on thick structural concrete members, where the path lengths may be anywhere from 300 mm in the case of columns to 23 m in mass gravity dams.
- However, in the laboratory where generally small specimens are used, the path length can affect the pulse velocity readings.

3. Temperature of concrete:

- It has been reported that variations of the ambient temperature between 5° C and 30° C do not significantly affect the pulse velocity measurements in concrete.
- At temperatures between 30° C and 60°C, there is up to 5% reduction in pulse velocity. This is probably due to the initiation of micro cracking in concrete.
- At below freezing temperature, the free water freezes within concrete thus resulting in an increase in pulse velocity. At 4° C, an increase of up to 7.5% in the pulse velocity through water-saturated concrete has been reported.

4. Moisture condition of concrete:

- In general, pulse velocity through concrete increases with increased moisture content of concrete. This influence is more marked for low-strength concrete than high strength concrete. It is considered that the pulse velocity of saturated concrete may be about 2% higher than that of similar dry concrete

5. Presence of reinforcing steel:

- The presence of reinforcing steel in concrete considerably affects the pulse velocity measurements because pulse velocity in steel is 1.2 to 1.9 times the velocity in plain concrete, thus pulse velocity measurements taken near the steel reinforcing bars may be high and may not represent the true velocity in concrete.

GENERAL GUIDELINES FOR CONCRETE QUALITY BASED ON UPV

PULSE VELOCITY	CONCRETE QUALITY
>4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and loss of integrity exist.

CHLORIDE ION TEST

Chloride Content Test on Concrete Structures

- Chloride content can be determined from broken samples or core samples of concrete.
- Primarily the level of chloride near the steel-concrete interface is of prime importance. Chloride present in concrete are fixed (water insoluble) as well as free (water soluble).
- Though it is the water soluble chloride ions, which are important from corrosion risk point of view, yet total acid soluble (fixed as well as free) chloride contents are determined and compared with limiting values specified for the concrete to assess the risk of corrosion in concrete.
- The total acid soluble chloride are determined in accordance with IS:14959 Part – III – 2001, whereas for assessment of water soluble chlorides the test consists of obtaining the water extracts, and conducting standard titration experiment for determining the water soluble chloride content and is expressed by water soluble chloride expressed by weight

- The method gives the average chloride content in the cover region. Further a chloride profile across the cover thickness will be a more useful measurements as this can help to make a rough estimate on chloride content diffusion rate.
- One recent development for field testing of chloride content includes the use of chloride ion sensitive electrode. This is commercially known as “Rapid Chloride test”
- The test consists of obtaining powdered samples by drilling and collecting them from different depths (every 5mm), mixing the sample (of about 15.g weight) with a special chloride extraction liquid, and measuring the electrical potential of the liquid by chloride-ion selective electrodes.
- With the help of a calibration graph relating electrical potential and chloride content, the chloride content of the samples can be directly determined.

Table-1: Guidelines for Identification for Corrosion Prone Locations based on Chemical Analysis

Chemical Test Results	Interpretations
High pH values greater than 11.5 and very low chloride content	No corrosion
High pH values and high chloride content greater than threshold values (0.15 % by weight of cement)	Corrosion prone
Low pH values and high chloride content (greater corrosion prone than threshold values of chloride 0.15% by weight of cement.	Increased risk of corrosion

CARBONATION TEST

Carbonation Test on Concrete Structures

- This test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture causing a reduction in level of alkalinity of concrete.
- A spray of 0.2% solution of phenolphthalein is used as pH indicator of concrete.
- The change of colour of concrete to pink indicates that the concrete is in the good health, where no changes in colour takes place, it is suggestive of carbonation-affected concrete.
- The test is conducted by drilling a hole on the concrete surface to different depths upto cover concrete thickness, removing dust by air blowing, spraying phenolphthalein with physician's injection syringe and needle on such freshly drilled broken concrete and observing change in colour.
- The depth of carbonation is estimated based on the change in colour profile.
- The pH value can also be determined by analysing samples of mortar collected by drilling from the site, dissolving the same in distilled water and thereby titrating in laboratory.

REINFORCEMENT COVER MEASUREMENT – COVERMETER TEST

- **Covermeter** are devices that give information about concrete cover to steel reinforcement using magnetic fields.
- Magnetic instruments for locating reinforcing steel present within in concrete work on the principle that the steel affects the alternating magnetic field.
- When a hand-held search unit is moved along the concrete surface, a beep indicates that the unit is located directly above a reinforcing bar.
- These meters can also be used to estimate the depth of a bar if its size is known, or estimate the bar size if the depth of cover is known.
- However, detailed calibration is needed to get satisfactory results.
- The bars may be located within 175 mm of the concrete mass but the method is not effective in heavily reinforced sections, sections with two or more adjacent bars or nearly adjacent layers of reinforcement.
- Inaccurate results may occur when the depth of concrete cover is equal to or close to the spacing of the reinforcing bars.
- During this test, steel or other metals must not be present close to the area under examination.
- Some results from tests must be calibrated by chipping of concrete to confirm concrete cover and bar size.

- Modern rebar detectors use different coil arrangements to generate several magnetic fields.
- Advanced signal processing supports not only the localization of rebars but also the determination of the cover and the estimation of the bar diameter.
- This method is unaffected by all non conductive materials such as concrete, wood, plastics, bricks, etc. However any kind of conductive m will have an influence on t

Advantages :

- high accuracy
- not influenced by moisture and heterogeneities of the concrete[1]
- unaffected by environmental influences
- low costs

Disadvantages :

- Limited detection range
- Minimum bar spacing depends on cover depths

PULL OUT TEST

INTRODUCTION

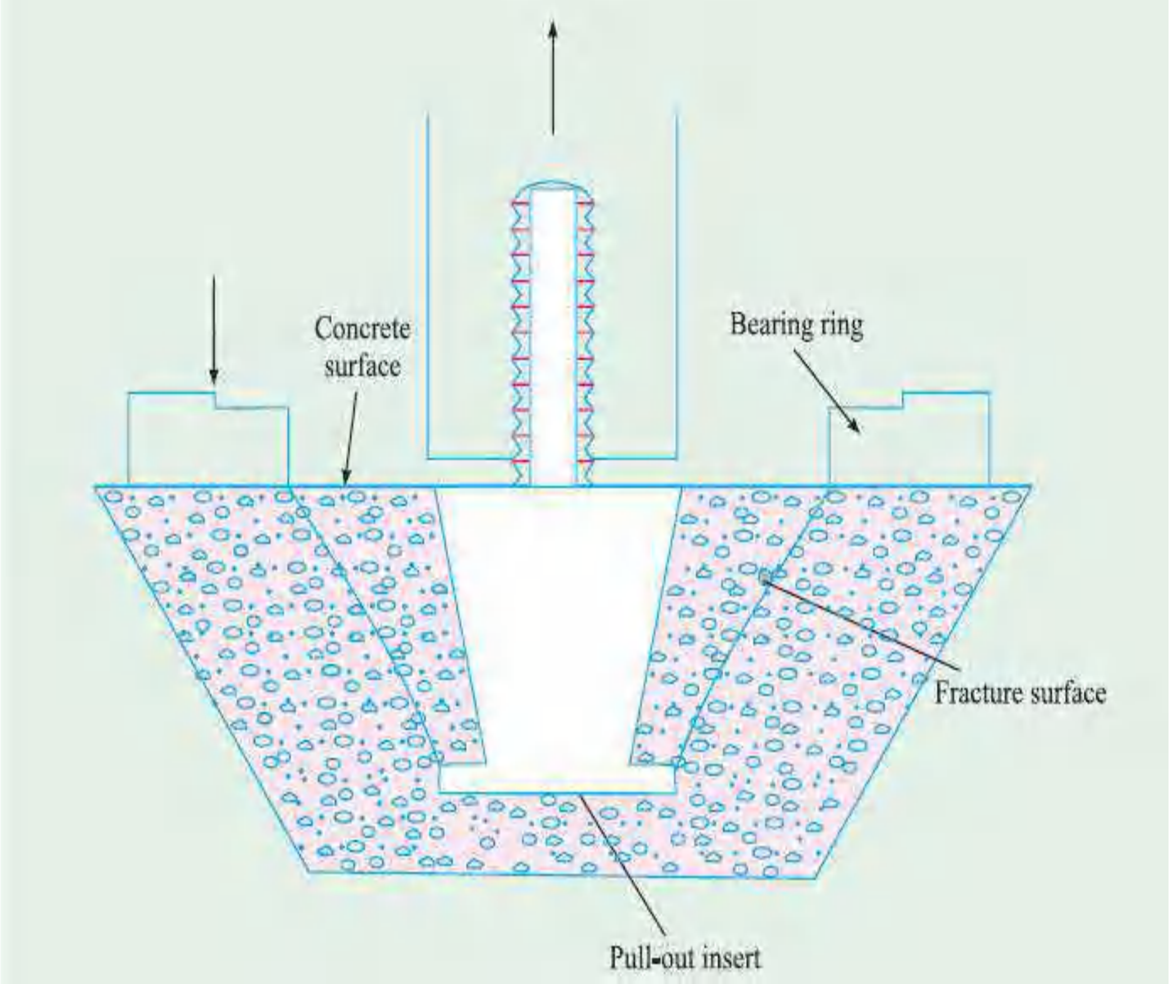
- The Pull out test was developed in England, with the aim of determining the strength of concrete
- This test can also be used to verify the adhesion strength of the concrete repairing material
- The technique is effective for use in beams and slabs and also shows appropriate application in structural elements of short section

Purpose

- To evaluate the in-place bond strength between a repair overlay and the substrate
- To evaluate the in-place tensile strength of concrete or other materials
- To evaluate the effect of surface preparation procedures on the tensile strength of the substrate before applying a repair material or overlay

Principle

- A disc is bonded to a prepared testing surface
- and the disc is pulled off after a partial core has been cut around the disc
- The pull-out force, F, is divided by the cross-sectional area of the partial core to obtain the pulloff strength .



Procedure

1.Surface planing

- The surface is ground with a diamond studded planning tool to expose the aggregates and to obtain a plane surface
- The dry surface is steel brushed and any dust or powder is blown away

2. Bonding the disc

- A clean disc is bonded to the prepared surface using a rapid-curing adhesive
- The progress of hardening is observed in the small cup in which the two component GRA was mixed
- In cold weather conditions, the concrete surface and the disc are heated with a heat gun to accelerate curing of the adhesive

3. Partial coring

- A partial core is cut perpendicular to the surface using cooling water; the bonded disc serves as a drill guide
- The partial core is cut with the CORECASE
- For tests to measure bond strength, the core is cut to a depth of 25 mm into the substrate or one-half of the core diameter, whichever is greater; for tensile strength of the substrate, cut to a depth of 25 mm

4. Pull-off

- The disc is loaded in direct tension at a controlled rate using a calibrated hydraulic pull machine
- The machine bears against a circular counter pressure ring positioned centrally on the planed surface
- The peak force in kN is recorded and used to obtain the pull-off strength by dividing by the cross sectional area of the partial core, is recorded

- Before starting up the bonding of metallic discs in the concrete surface, the surfaces were prepared to obtain good adhesion
- This procedure is adopted mainly for removal of the cement paste on the concrete surface and to make the aggregate apparent

Disadvantages

- Increases the time for test because depends on bonding a metallic disc on the surface of the concrete.
- The cost of the equipment is high
- Impossibility of its execution in high-strength concrete due to load limitations equipment availability

Advantages

- feasible to be employed to estimate the strength of concrete in situ
- Both surface and internal discontinuity can be detected
  Significant variations in composition can be detected


THANK YOU

MODULE-4

CONTENTS

STRENGTH OF CONCRETE

- Strength is the most commonly considered valuable property of concrete although in many other practical cases other characteristics such as durability and permeability are important.
- The strength of concrete is almost invariably a vital element of structural design.
- Strength of concrete is defined as ultimate load that causes failure (or is its resistance to rupture) and its unit are force units divided by area.

TYPES OF CONCRETE STRENGTH

- COMPRESSIVE STRENGTH
- TENSILE STRENGTH
- FLEXURAL STRENGTH

COMPRESSIVE STRENGTH

- Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.
- Compressive strength test is carried out on concrete cube, cylinder, prism.

TENSILE STRENGTH

- Although concrete is not designed to resist tension, the knowledge of tensile strength is of value in estimating the load under which the crack will develop.
- The absence of cracking is of considerable importance in maintaining the continuity of a concrete structure and in many cases in the prevention of corrosion of reinforcement.
- Direct measurement of tensile strength of concrete is difficult.
- Two types of test : Direct tension test and Split tensile test

1. DIRECT TENSION TEST

- Direct methods suffer from a number of difficulties related to holding the specimen properly in the test machine without introducing stress concentration and to the application of load without eccentricity.

- Tensile strength can be estimated by:

➢ $0.75\sqrt{f_{ck}}$ (IS 456)

➢ 10% of compressive strength

2. SPLIT TENSILE STRENGTH

- In this test the concrete cylinder of the type used for compression tests is placed with its axis horizontal between the plates of testing machine and the load is increased until failure by indirect and splitting along the vertical diameter takes place.
- Tensile strength, $\boldsymbol{\sigma}_t = \frac{2P}{\pi l D} = \frac{0.637P}{lD}$

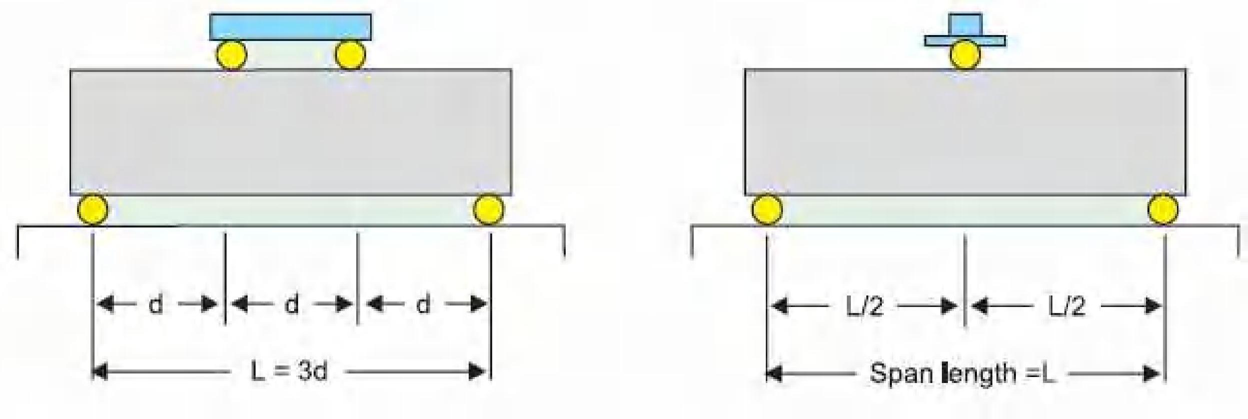
Where, P= max total load on the beam

l = span

D = diameter of specimen

FLEXURAL STRENGTH

- The flexural tensile strength at failure or the modulus of rupture is determined by loading a prismatic concrete beam specimen.
- Concrete is subjected to flexural loads more often than tensile loads.
- Flexural strength ,$f_b = 0.7\sqrt{f_{ck}}$ (IS 456)



Two point loading/Four point loading   Three point loading

- Specimen size: 15 X 15 X 70 cm or 10 X10 X 50 cm

- 3 cases:

1. a>20cm (15cm specimen) & a> 13.3cm (10cm specimen)

   Flexural strength, $f_b = \frac{Pl}{bd^2}$

2. a<20cm but >17cm (15cm specimens) or a<13.3cm but >11cm (10cm specimen)

   Flexural strength, $f_b = \frac{3Pa}{bd^2}$

3. a<17cm (15cm specimen) & a<11cm (10cm specimen) - Discard

Where, P= max total load on the beam

l = span

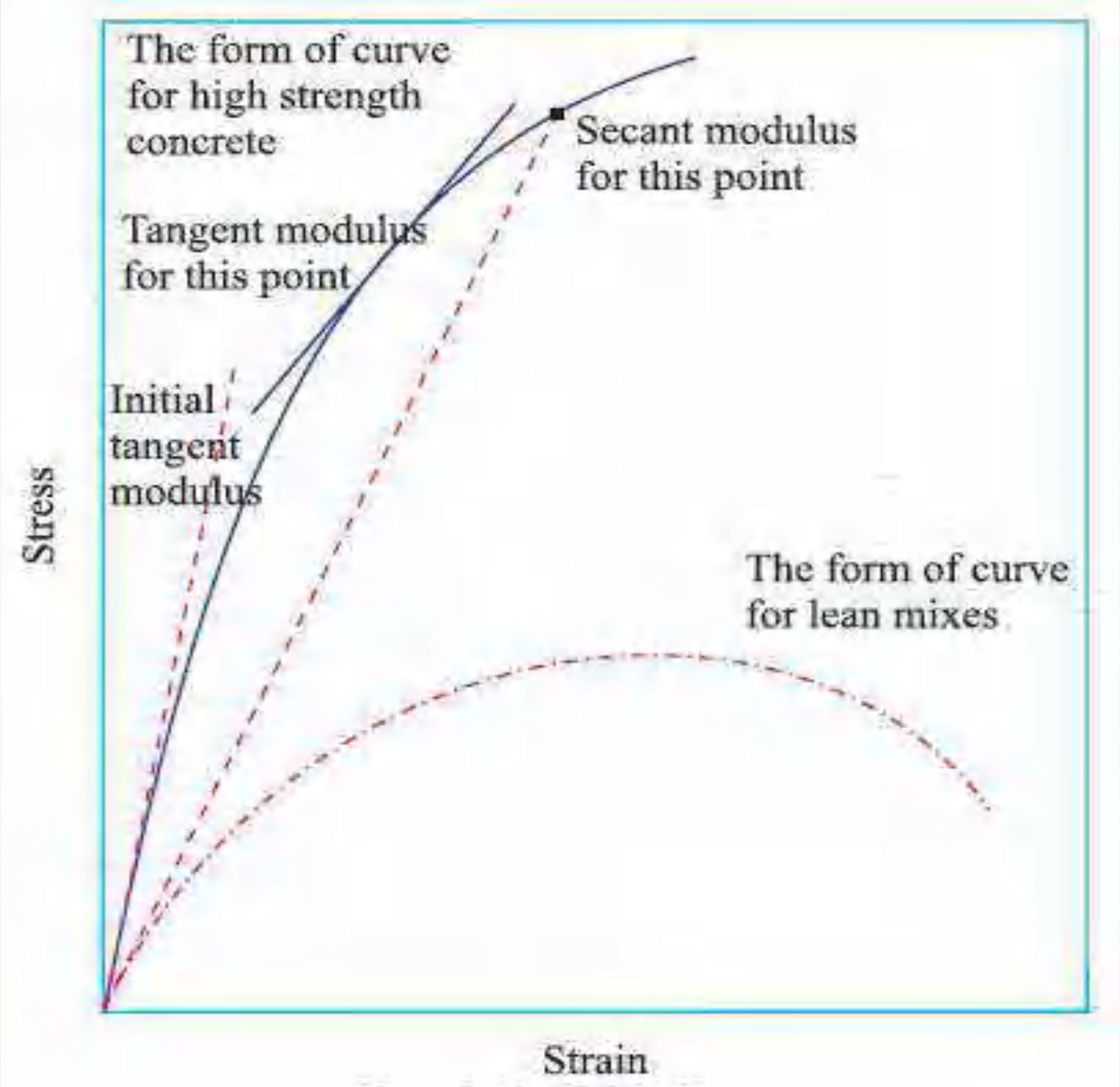
b = width of beam

d = depth of beam

a = distance between line of fracture and nearest support

ELASTIC PROPERTIES OF CONCRETE

- Modulus of elasticity, E_c = $5000\sqrt{f_{ck}}$ (IS 456)
- The modulus of elasticity is determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformations by means of dial gauges fixed between certain gauge length.
- Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross-section will give the stress.
- A series of readings are taken and the stress-strain relationship is established.



1. The Initial Tangent Modulus

Slope of the line drawn to stress - strain curve at origin

2. The Tangent Modulus

Slope of the line drawn tangent to stress-strain curve at any point on the curve

3. The Secant Modulus

Slope of the line drawn from origin to a point on the curve corresponding to 40% stress of the failure stress

4. The chord Modulus

Slope of the line between two points on the stress - strain curve

The modulus of elasticity most common used in practice is secant modulus.

FACTORS AFFECTING MODULUS OF ELASTICITY

- Age

  Increases with age

- Rich mix

  Increases with rich mix

- Quantity and quality of aggregates (Modulus of elasticity of aggregates)

  Increases with good quality of aggregates

  Increases when the quantity of aggregates increases

- Strength of concrete

  Increases with higher strength concretes (related to age)

CREEP

- Creep can be defined as "time-dependent" part of strain resulting from stress.
- The gradual increase in strain, without increase in stress, with the time is due to creep.
- Creep can also be defined as the increase in strain under sustained stress.
- When the sustained load is removed, the strain decreases immediately by an amount equal to elastic strain at the given age. This is called instantaneous recovery.
- This is followed by gradual decrease in strain and is called creep recovery.

FACTORS AFFECTING CREEP

- Influence of aggregates

- Aggregate undergoes very little creep.
- It is really the paste which is responsible for the creep.
- The grading, the shape, the maximum size of aggregate have been suggested as factors affecting creep.
- The modulus of elasticity of aggregate is one of the important factors influencing creep.
- It can be easily imagined that the higher the modulus of elasticity the less is the creep.

- Influence of mix proportion

- The amount of paste content and its quality is one of the most important factors influencing creep.
- A poorer paste structure undergoes higher creep.
- Therefore, it can be said that creep increases with increase in w/c ratio.
- In other words, it can also be said that creep is inversely proportional to the strength of concrete.

- Influence of Age

- The quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more.
- The moisture content of the concrete being different at different age, also influences the magnitude of creep.

EFFECTS OF CREEP

- In reinforced concrete columns, creep property of concrete is useful. Under load immediately elastic deformation takes place. Concrete creeps and deforms. However, in eccentrically loaded columns, creep increases the deflection and can load to buckling.

- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.

- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.

- Loss of prestress due to creep of concrete in prestressed concrete structure is well known and provision is made for the loss of prestress in the design of such structures.

SHRINKAGE

- The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.
- The following are the different types of shrinkage.

➢ Plastic Shrinkage

➢ Drying Shrinkage

➢ Autogeneous Shrinkage

➢ Carbonation Shrinkage

1. PLASTIC SHRINKAGE

- Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state.
- Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade is believed to be the reasons of plastic shrinkage.
- The loss of water results in the reduction of volume.
- In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage.
- Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out the surface concrete collapses causing cracks.

- Plastic concrete is sometimes subjected to unintended vibration or yielding of formwork support which again causes plastic shrinkage cracks as the concrete at this stage has not developed enough strength.
- From the above it can be inferred that high water/cement ratio, badly proportioned concrete, rapid drying, greater bleeding, unintended vibration etc, are some of the reasons for plastic shrinkage it can also be further added that richer concrete undergoes greater plastic shrinkage.
- Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface.
- This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by monomolecular coatings by fog spray that keeps the surface moist; or by working at night.

- An effective method of removing plastic shrinkage cracks is to revibrate the concrete in a controlled manner.
- Use of small quantity of aluminium power is also suggested to offset the effect of plastic shrinkage.
- Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.
- Further, use of unneeded high slump concrete, over sanded mix, higher air entraining should be discouraged in order to reduce the higher plastic shrinkage.

2. DRYING SHRINKAGE

- Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions.
- The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen.
- The loss of free water contained in hardened concrete does not result in any appreciable dimension change.
- It is the loss of water held in gel pores that causes the change in the volume.
- Under drying conditions the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions.
- It is theoretically estimated that the total linear change due to long time drying shrinkage could be of the order of $10{,}000 \times 10^{-6}$.
- But the value up to $4{,}000 \times 10^{-6}$ has been actually observed.

- Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate.
- The magnitude of drying shrinkage is also a function of the fineness of gel.
- The finer the gel the more is the shrinkage.
- It has been pointed out earlier that the high pressure steam cured concrete with low specific surface of gel, shrinks much less than that of normally cured cement gel.

3. AUTOGENEOUS SHRINKAGE

- In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur.
- The shrinkage of such a conservative system is known as autogeneous shrinkage.
- Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam.
- The magnitude of autogeneous shrinkage is in the order of about 100×10^{-6}

4. CARBONATION SHRINKAGE

- Carbonation shrinkage is a phenomenon very recently recognised.
- Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement.
- Calcium hydroxide $Ca(OH)_2$ gets converted to calcium carbonate and also some other cement compounds are decomposed.
- Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere.
- Carbonation penetrates beyond the exposed surface of concrete only very slowly.
- The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium.

- Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.
- Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place.
- As the new product is less in volume than the product replaced, shrinkage takes place.
- Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste.
- As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance.
- But carbonation reduces the alkalinity of concrete which gives a protective coating to the reinforcement against rusting.
- If depth of carbonation reaches upto steel reinforcements, the steel becomes liable for corrosion.

FACTORS AFFECTING SHRINKAGE

- One of the most important factors that affects shrinkage is the drying condition or in other words, the relative humidity of the atmosphere at which the concrete specimen is kept.
- If the concrete is placed in 100 per cent relative humidity for any length of time, there will not be any shrinkage, instead there will be a slight swelling.
- The rate of shrinkage decreases rapidly with time.
- It is observed that 14 to 34 per cent of the 20 year shrinkage occurs in 2 weeks, 40 to 80 per cent of the 20 year shrinkage occurs in 3 months and 66 to 85 per cent of the 20 year shrinkage occurs in one year.
- Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete.
- The richness of the concrete has a significant influence on shrinkage.

- Aggregate plays an important role in the shrinkage properties of concrete.
- The quantum of an aggregate, its size, and its modulus of elasticity influence the magnitude of drying shrinkage.
- The grading of aggregate by itself may not directly make any significant influence.
- But since it affects the quantum of paste and water/cement ratio, it definitely influences the drying shrinkage indirectly.
- The aggregate particles restrain the shrinkage of the paste.
- The harder aggregate does not shrink in unison with the shrinking of the paste whereby it results in higher shrinkage stresses, but low magnitude of total shrinkage.
- But a softer aggregate yields to the shrinkage stresses of the paste and thereby experiences lower magnitude of shrinkage stresses within the body, but greater magnitude of total shrinkage.

THE END

MODULE 3

1. MINERAL ADMIXTURES
2. PROPORTIONING OF CONCRETE MIXTURES

1.MINERAL ADMIXTURES

MINERAL ADMIXTURES

- These are Pozzolanic materials
- Pozzolans are siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds, possessing cementitious properties.
- The reaction can be shown as

  Pozzolan + Calcium Hydroxide + Water → C – S – H (Gel)
- This reaction is called pozzolanic reaction.

Advantages of pozzolana:

It has been amply demonstrated that the best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

- Lower the heat of hydration and thermal shrinkage;
- Increase the water tightness;
- Reduce the alkali-aggregate reaction;
- Improve resistance to attack by sulphate soils and sea water;
- Lower susceptibility to dissolution and leaching;
- Improve workability;
- Lower costs.

Pozzolanic materials can be divided into two groups: natural pozzolana and artificial pozzolana.

Natural Pozzolans

- Clay and Shales
- Opalinc Cherts
- Diatomaceous Earth
- Volcanic Tuffs and Pumicites.

Artificial Pozzolans

- Fly ash
- Blast Furnace Slag
- Silica Fume
- Rice Husk ash
- Metakaoline

Artificial Pozzolans

1. Fly Ash:

- Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator.
- In U.K. it is referred as pulverised fuel ash (PFA).
- Fly ash is the most widely used pozzolanic material all over the world.

There are two ways that the fly ash can be used:

- Intergrind certain percentage of fly ash with cement clinker at the factory to produce Portland pozzolana cement (PPC)
- Use the fly ash as an admixture at the time of making concrete at the site of work.
- The latter method gives freedom and flexibility to the user regarding the percentage addition of fly ash.

Physical characteristics of fly ash:

- Fine grained material mostly consisting of spherical glassy particles
- Some ashes also contains irregular or angular particles

Size and shape of fly ash:

- Size depends on the source
- Some may be finer or coarser than OPC
- Size ranging between 10 to 100 microns

Chemical composition of fly ash:

- Silicon dioxide - 30 to 60%
- Aluminium dioxide - 15 to 30%
- Unburnt carbon – upto 30%
- Calcium oxide - 1 to 7%
- Magnesium oxide – small amounts
- Sulphur trioxide – small amounts

Colour of fly ash:

- Tan to dark grey depending on chemical composition
- Tan and light colours – high lime content
- Brownish colour- high iron content
- Dark grey to black colour – elevated unburnt content

Fineness of fly ash:

- Dry and wet sieving are the commonly used measure

Specific gravity of fly ash:

- Ranges from 1.90 for sub-bituminous ash to 2.96 for iron rich bituminous ash

Classification of fly ash:

ASTM broadly classify fly ash into two classes:

- Class F: Fly ash normally produced by burning anthracite or bituminous coal, usually has less than 5% CaO. Class F fly ash has pozzolanic properties only.
- Class C: Fly ash normally produced by burning lignite or sub-bituminous coal. Some class C fly ash may have CaO content in excess of 10%. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

IS 3812-1981 classify fly ash in to two grades:

- Grade I fly ash: derived from bituminous coal having fractions $SiO_2 + Al_2O_3 + Fe_2O_3$ greater than 70%
- Grade II fly ash: derived from bituminous coal having fractions $SiO_2 + Al_2O_3 + Fe_2O_3$ greater than 50%

Effect of Fly Ash on Fresh Concrete:

- Use of right quality fly ash, results in reduction of water demand for desired slump. With the reduction of unit water content, bleeding and drying shrinkage will also be reduced.
- Replacement of cement with fly ash results in a reduction in the temperature rise in fresh concrete.

Effect of Fly Ash on Hardened Concrete:

- Fly ash contributes to the strength of concrete due to its pozzolanic reactivity. Since the pozzolanic reaction proceeds slowly, the initial strength of fly ash concrete tends to be lower than that of concrete without fly ash. Due to continued pozzolanic reactivity concrete develops greater strength at later age, which may exceed that of the concrete without fly ash.
- The pozzolanic reaction also contributes to making the texture of concrete dense, resulting in decrease of water permeability and gas permeability.
- Sufficiently cured concrete contaning good quality fly ash shows dense structure which offers resistance to infiltration of substance.
- Improves sulphate resistance
- Reduces the expansion due to alkali-aggregate reaction

Advantages of fly ash:

- Economical
- Environment friendly
- Fly ash has small particles which makes concrete highly dense and reduces permeability of concrete thereby adding strength to concrete
- Concrete mixture generates low heat of hydration which prevents thermal cracking
- Gives good workability, durability and finish

Disadvantages of fly ash:

- Quality of fly ash has to be vital. Poor quality has negative impacts on concrete
- Poor quality increases permeability of concrete
- Some fly ash cannot be actually improved for concrete, thus it is important to use only good quality fly ash to prevent negative effects on the structure.

2. Ground Granulated Blast Furnace Slag (GGBS)

- It is a non-metallic product consisting essentially of silicates and aluminates of calcium and other bases.
- The molten slag is rapidly chilled by quenching in water to form a glassy sand like granulated material.
- The granulated material when further ground to less than 45 micron will have specific surface of about 400 to 600 m^2/kg.

Chemical Composition

The chemical composition of Blast Furnace Slag is similar to that of cement clinker.

- Calcium oxide, CaO = 30 to 45%
- Silica, SiO_2 = 30 to 38%
- Alumina, Al_2O_3 = 15 to 25%
- Magnesia, MgO = 4 to 17%
- Iron oxide, Fe_2O_3 = 0.5 to 2%

Physical properties

- Colour: off white
- Specific Gravity: 2.9
- Bulk density: 1200 Kg/m^3
- Fineness: 350 m^2/Kg

Effect on fresh concrete

- The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump.
- This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag.
- In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement.

Effect on hardened concrete

- Exclusive research works have shown that the use of slag leads to the enhancement of intrinsic properties of concrete in both fresh and hardened conditions.

Strength gain

- Lower early strength
- Higher final strength

Heat Treatment

- Suits for GGBS very well
- Efficiency improves with increasing GGBS amount
- Higher temperatures can be applied.

Flexural strength

- The ratio between flexural and compressive strength is higher in GGBS concretes.

Durability against chemical loads

- If slag amount is > 50%, concrete possesses good chemical durability (especially against sulphates)
- Smaller $Ca(OH)_2$ amount, pH of pore water is diminished - lower capacity to hinder reinforcement corrosion.

Advantages

- Reduced heat of hydration and smaller risk for cracking in massive structures.
- Reduced permeabilities to the external agencies.
- Smaller water to binder ratio, higher strength
- Half the price compared to Portland cement
- Improved durability against chemical loads
- Improved flexural/ compressive strength ratio.

Disadvantages

- Additional quality control costs
- Slow and small hydration heat, not suitable in precast factories nor during winter concreting
- Faster carbonation rate, decreased service life span due to reinforcement corrosion
- Carbonation changes pore structure unfavourably with respect to durability
- Permeability increases at later age (carbonation)

3. Silica Fume

- Silica fume, also referred to as microsilica or condensed silica fume, is another material that is used as an artificial pozzolanic admixture.
- It is a product resulting from the manufacture of silicon or ferrosilicon alloy in an electric arc furnace.
- Silica fume rises as an oxidised vapour.
- It cools, condenses and is collected in cloth bags.
- It is further processed to remove impurities and to control particle size.

Chemical composition and physical characteristics

- Condensed silica fume is essentially silicon dioxide (more than 90%) in noncrystallineform.
- It has spherical shape.
- It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles.
- Silica fume has specific surface area of about 20,000 m^2/kg.

Available forms

Microsilica is available in the following forms:

- Undensifiedforms with bulk density of 200–300 kg/m^3
- Densifiedforms with bulk density of 500–600 kg/m^3
- Micro-pelletisedforms with bulk density of 600–800 kg/m^3
- Slurry forms with density 1400 kg/m^3

Influence on Fresh Concrete

- Water demand increases in proportion to the amount of microsilica added.
- The increase in water demand of concrete containing microsilica will be about 1% for every 1% of cement substituted.
- Measures can be taken to avoid this increase by adjusting the aggregate grading and using superplasticizers.
- The addition of microsilica will lead to lower slump but more cohesive mix. The microsilica make the fresh concrete sticky in nature and hard to handle.
- It was also found that there was large reduction in bleeding and concrete with microsilica could be handled and transported without segregation.

Influence on Hardened Concrete

- Concrete containing microsilica showed outstanding characteristics in the development of strength.
- Improvement in durability of concrete with microsilica.
- Resistance against frost damage.

4. Metakaolin

- Considerable research has been done on natural pozzolans, namely on ordinary clay and kaoliniticclay.
- These unpurified materials have often been called "Metakaolin".
- Although it showed certain amount of pozzolanic properties, they are not highly reactive.
- Highly reactive metakaolin is made by removing unreactive impurities to make 100% reactive pozzolan.
- Such a product, white or cream in colour, purified, thermally activated is called High Reactive Metakaolin (HRM).
- High reactive metakaolin shows high pozzolanic reactivity and reduction in $Ca(OH)_2$ even as early as one day.
- It is also observed that the cement paste undergoes distinct densification.
- The improvement offered by this densification includes an increase in strength and decrease in permeability.

- The average size of highly reactive metakaolin particle, which is smaller than cement particles, is ranging from 1 to 2 and it is white in colour which in return influences the colour of the final product.
- Specific gravity of highly reactive metakaolin is 2.5.

Advantages in concrete

1. Boosts compressive strength
   - The Calcium hydroxide, which forms up to 25% of hydrated Portland cement, does not contribute to concretes durability or strength.
   - What metakaolin does is to combine with the calcium hydroxide and produce added cementing compounds, which makes the concrete stronger.
2. Greater impermeability
   - The pozzolanic and hydraulic reactions of ultrafine metakaolin, results in densification of the micro structure.
   - This makes the resultant concrete withstand varied conditions and helps in adding to its long term durability.

3. Easier finishing and better pumpability

- Use of mineral admixture like metakaolin gives concrete a non-sticky and creamy texture.
- Also helps in making concrete easier to pump to greater distances, either vertically or horizontally.

4. Reduction in efflorescence

- When calcium hydroxide present in the concrete mixture reacts with atmospheric carbon dioxide the result is the whitish haze, commonly known as efflorescence.
- Since calcium hydroxide is consumed by metakaolin, its use helps reduce efflorescence to a large extent.

5. A green option

- The mineral admixture helps in obtaining energy savings; apart from helping to reduce greenhouse gas emissions.

7. Early strength development

- Metakaolin helps in improving early strength development of concrete without appreciable loss of workability.

8. Cost effective option and availability

- Less amount of chemical admixtures compared to other mineral admixtures
- Abundant local availabilty

5. Rice husk ash

- Rice husk ash, is obtained by burning rice husk.
- These exhibits high pozzolanic characteristics.
- The properties are greatly affected by the burning conditions.
- The large amount of unburnt carbon due to the incomplete combustion exist and make the colour of rice husk ash is black, whereas, the burning is done under enough air supply condition the rice husk ash become grey and white.
- The white rice husk ash has better quality compared to the black rice husk ash due to the existence of carbon affecting adversely on the reactivity.

Chemical composition

Sl no:	Paticulars	Proportion
1.	Silicon Diodixe	86.94%
2.	Aluminium Oxide	0.2%
3.	Iron Oxide	0.1%
4.	Calcium Oxide	0.3 – 2.25%
5.	Magnesium Oxide	0.2 – 0.6%
6.	Sodium Oxide	0.1 – 0.8%
7.	Potassium Oxide	2.15 – 2.30%

- Rice husk ash has a specific gravity around 2.05 with a particle size less than 45 micron.

Variation of properties of concrete with rice husk

The incorporation of rice husk ash in concrete convert it into an eco-friendly supplementary cementitious material.

The following properties of the concrete are altered with the addition of rice husk:

- Due to addition of rice husk ash, concrete becomes cohesive and more plastic and thus permits easier placing and finishing of concrete. It also increases workability of concrete.
- The heat of hydration is reduced. This itself help in drying shrinkage and facilitate durability of the concrete mix.
- The reduction in the permeability of concrete structure. Reduce corrosion and increase durability of concrete strength.

2. PROPORTIONING OF CONCRETE MIXTURES

Introduction

- The process of selecting suitable ingredients of concrete and determining their proportions is referred to as mix design.
- The objective is producing a concrete of the required, strength, durability, and workability as economically as possible.
- The proportioning of ingredient of concrete is governed by the required performance of concrete in two states, namely the plastic and the hardened states.
- If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability therefore becomes important.
- The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors like quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing.

Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are :

- The minimum compressive strength required from structural consideration
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

Types of Mixes

1. **Nominal Mixes**

- In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates.
- These offer simplicity and under normal circumstances, have a margin of strength above that specified.

2. **Standard mixes.**

- The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.
- IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

3. Designed Mixes

- In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete.
- The approach results in the production of concrete with the appropriate properties most economically.

Factors considered in the design of mix

The various factors affecting the mix design are:

1. Compressive strength

- It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete.
- The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix.
- The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction.
- According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

2. Workability

- The degree of workability required depends on three factors.
- These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used.
- For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort.

3. Durability

- The durability of concrete is its resistance to the aggressive environmental conditions.
- High strength concrete is generally more durable than low strength concrete.

4. Maximum nominal size of aggregate

- In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate.
- However, the compressive strength tends to increase with the decrease in size of aggregate.
- IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

5. Grading and type of aggregate

- Coarser the grading leaner will be mix which can be used.
- Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.
- The type of aggregate influences strongly the aggregate-cement ratio.

6. Quality Control

- The degree of control can be estimated statistically by the variations in test results.
- The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing.

Various Methods of Proportioning

(a) Arbitrary proportion

(b) Fineness modulus method

(c) Maximum density method

(d) Surface area method

(e) Indian Road Congress, IRC 44 method

(f) High strength concrete mix design

(g) Mix design based on flexural strength

(h) Road note No. 4 (Grading Curve method)

(i) ACI Committee method

(j) DOE method

(k) Mix design for pumpable concrete

(l) IS method (IS 10262-2009)

1. BIS METHOD (IS METHOD)

1. BIS METHOD

- IS method is explained in IS code IS 10262-2009

Data for mix proportioning

- The following data are required for mix proportioning of a particular grade of concrete:

a) Grade designation:

b) Type of cement;

c) Maximum nominal size of aggregate;

d) Minimum cement content:

e) Maximum water-cement ratio;

f) Workability

g) Exposure conditions as per Table 4 and Table 5 of IS -456;

h) Maximum temperature of concrete at the time of placing

j) Method of transporting and placing;

k) Early age strength requirements, if required:

l) Type of aggregate

m) Maximum cement content; and

n) Whether an admixture shall or shall not be used and the type of admixture and the condition of use

Selection of mix proportions

1. Selection of Water-Cement Ratio

- Different cements, supplementary cementitious materials and aggregates of different maximum size, grading, surface texture, shape and other characteristics may produce concretes of different compressive strength
- Therefore, the relationship between strength and free water-cement ratio should preferably be established for the materials actually to be used
- The water-cement ratio given in Table 5 of IS 456 for respective environment exposure conditions may be used as starting point.

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
ii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

2. Selection of Water Content

- The water content of concrete is influenced by a number of factors, such as aggregate size, aggregate shape, aggregate texture, workability, water-cement ratio, cement and other supplementary cementitious material type and content, chemical admixture and environmental conditions.
- The quantity of maximum mixing water per unit volume of concrete may be determined from Table 2 of 10262-2009

Table 2 Maximum Water Content per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate

Sl No.	Nominal Maximum Size of Aggregate mm	Maximum Water Content [1)] kg
(1)	(2)	(3)
i)	10	208
ii)	20	186
iii)	40	165

3. Calculation of Cementitious Material Content

- The cement and supplementary cementitious material content per unit volume of concrete may be calculated from the free water-cement ratio and the quantity of water per unit volume of concrete.

4. Estimation of Coarse Aggregate Proportion

- Approximate values for aggregate volume are given in Table 3 for a water-cement ratio of 0.5, which may be suitably adjusted for other water cement ratios.
- It can be seen that for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and grading zone of fine aggregate.

Table 3 Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate

Sl No.	Nominal Maximum Size of Aggregate mm	Volume of Coarse Aggregate[1] per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zone I
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69

5.Estimation of Fine Aggregate Proportion

- With the completion of procedure given in 4, all the ingredients have been estimated except the coarse and fine aggregate content.
- The coarse and fine aggregate contents are then determined by multiplying with their respective specific gravities .

6.Trial Mixes

- The calculated mix proportions shall be checked by means of trial batches.

2. ACI METHOD
(American Concrete Institute)

2. ACI METHOD

Data to be collected

(i) Fineness modulus of selected F.A.

(ii) Unit weight of coarse aggregate.

(iii) Sp. gravity of coarse and fine aggregates

(iv) Absorption characteristics of both coarse and fine aggregates.

(v) Specific gravity of cement.

Selection of mix proportions

The procedure is as follows:

Step 1. Choice of slump

Step 2. Choice of maximum size of aggregate

Step 3. Estimation of mixing water and air content

Step 4. Selection of water/cement ratio

Step 5. Calculation of cement content

Step 6. Estimation of coarse aggregate content

Step 7. Estimation of Fine Aggregate Content

Step 8. Adjustments for Aggregate Moisture

Step 9. Trial Batch Adjustments

1. Choice of slump

- If slump is not specified, a value appropriate for the work can be selected from the below Table

Type of Construction	Slump	
	(mm)	(inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

2. Choice of maximum size of aggregate.

- Large maximum sizes of aggregates produce less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement.
- In practice the dimensions of the forms or the spacing of the rebars controls the maximum CA size.
- ACI 211.1 states that the maximum CA size should not exceed:
  - one-fifth of the narrowest dimension between sides of forms,
  - one-third the depth of slabs,
  - 3/4-th of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

3. Estimation of mixing water and air content

- The quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum CA size, the shape and grading of CA and FA, as well as the amount of entrained air.

	Mixing Water Quantity in kg/m³ (lb/yd³) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

4. Selection of water/cement ratio

- The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 10.3 and/or Table 10.4.

Table 10.3: Water-Cement Ratio and Compressive Strength Relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table 10.4 Maximum Permissible Water/Cement Ratios For Concrete In Severe Exposures

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

5. Calculation of cement content

- The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

6. Estimation of coarse aggregate content

- The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	2.60	2.80	3.00
9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

7. Estimation of Fine Aggregate Content

- At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate.
- Then once the volumes are known, the weights of each ingredient can be calculated from the specific gravities

8. Adjustments for Aggregate Moisture

Aggregate weights

- Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

Amount of mixing water

- The batched aggregate absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

9. Trial Batch Adjustments.

- The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.

THE END

Module 2

Workability of concrete

It is the ease with which concrete is mixed, transported, placed and compacted with minimum loss of homogeneity. Road research laboratory U.K defined workability as the property of concrete which determines the amount of useful internal work necessary to produce full compaction. It is also defined as ease with which concrete can be compacted 100% having regard to mode of compaction and place of deposition.

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming.

Factors affecting workability

(*a*) Water Content
(*b*) Mix Proportions
(*c*) Size of Aggregates
(*d*) Shape of Aggregates
(*e*) Surface Texture of Aggregate
(*f*) Grading of Aggregate
(*g*) Use of Admixtures.

(*a*) Water Content: Water content in a given volume of concrete, will have significant influences 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 factors affecting workability.

(*b*) Mix Proportions: Aggregate/cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the 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. On the other hand, 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.

(*c*) Size of Aggregate: The bigger the size of the aggregate, the less 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.

(*d*) Shape of Aggregates: The shape of aggregates influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it 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.

(*e*) 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.

rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

(*f*) 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. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.

(*g*) Use of Admixtures: Of all the factors mentioned above, the most import factor which affects the workability is the use of admixtures.
plasticizers and superplasticizers greatly improve the workability many folds.

Use of air-entraining agent being surface-active, reduces the internal friction between the particles. They also act as artificial fine aggregates of very smooth surface. It can be viewed that air bubbles act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, inspite of increasing the surface area, offer better lubricating effects for giving better workability.

Measurement of workability

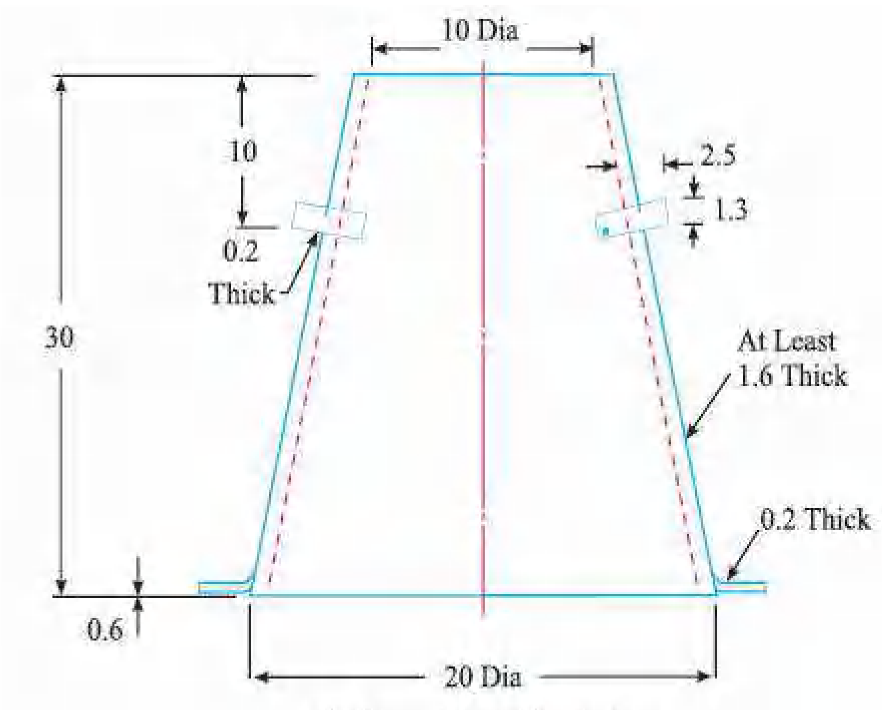
(*a*) Slump Test
(*b*) Compacting Factor Test
(*c*) Flow Test
(*d*) Kelly Ball Test
(*e*) Vee Bee Consistometer Test.

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. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. However, it is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch.

The appartus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as under:

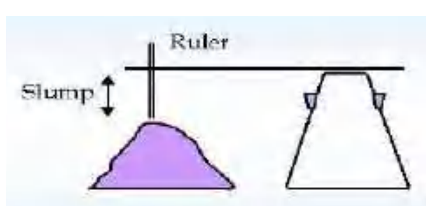
Bottom diameter	:	20 cm
Top diameter	:	10 cm
Height	:	30 cm

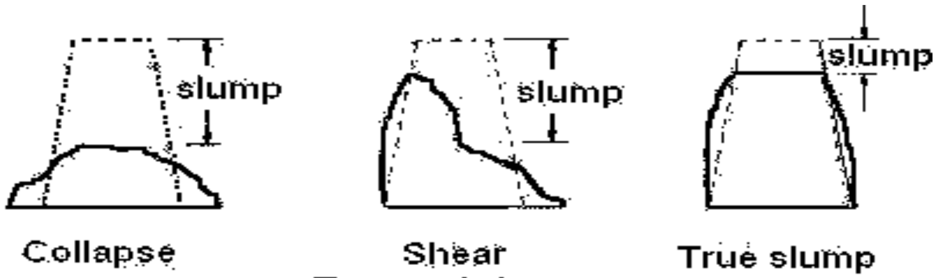


All dimensions in Centimeters

The thickness of the metallic sheet for the mould should not be thinner than 1.6mm. Sometimes the mould is provided with suitable guides for lifting vertically up. For tamping the concrete, a steel tamping rod 16mm dia 0.6m long with bullet end is used. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal rigid and non-absorbent surface. The mould is then filled in four layers, each separately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping tamping rod taking

care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as SLUMP of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete.





Types of slump

The pattern of slump is shown in Fig. It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slamp. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation.

From IS 456-2000

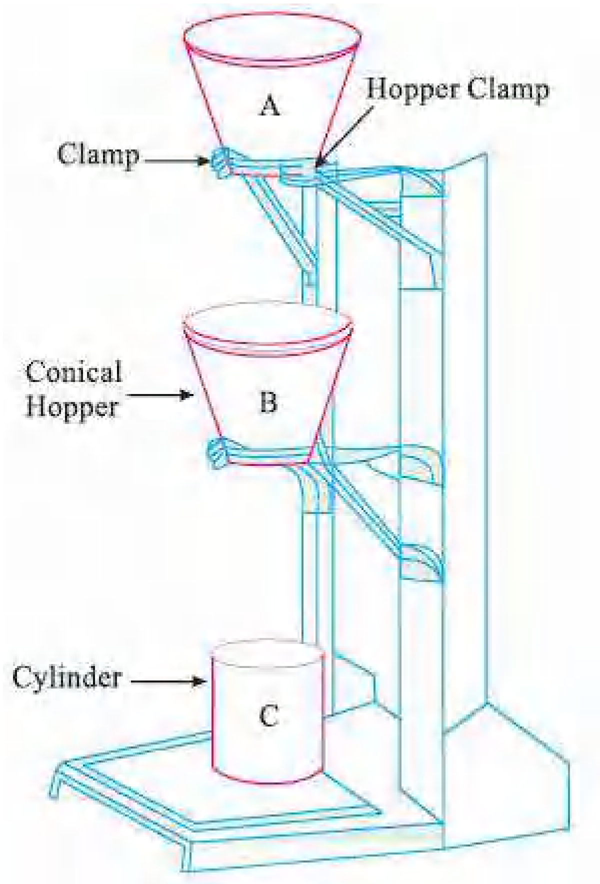
Placing Conditions	*Degree of Workability*	*Slump* (mm)
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* 7.1.1
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns; Slipform work; Pumped concrete	Medium	50-100 75-100
Trench fill; *In-situ* piling	High	100-150
Tremie concrete	Very high	*See* 7.1.2

7.1.1 In the 'very low' category of workability where strict control is necessary, for example pavement quality concrete, measurement of workability by determination of compacting factor will be more appropriate than slump (*see* IS 1199) and a value of compacting factor of 0.75 to 0.80 is suggested.

7.1.2 In the 'very high' category of workability, measurement of workability by determination of flow will be appropriate (*see* IS 9103).

Compacting Factor Test

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 as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test.



Essential Dimension of the Compacting Factor Appartus for use with Aggregate not exceeding 40 mm Nominal Max. Size

	Dimension cm
Upper Hopper, A	
Top internal diameter	25.4
Bottom internal diameter	12.7
Internal height	27.9
Lower hopper, B	
Top internal diameter	22.9
Bottom internal diameter	12.7
Internal height	22.9
Cylinder, C	
Internal diameter	15.2
Internal height	30.5
Distance between bottom of upper hopper and top of lower hopper	20.3
Distance between bottom of lower hopper and top of cylinder	20.3

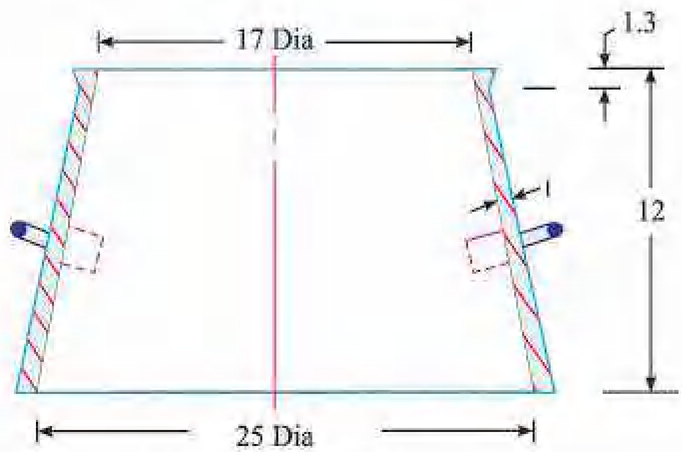
The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that 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 upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as "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. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as "Weight of fully compacted concrete".

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

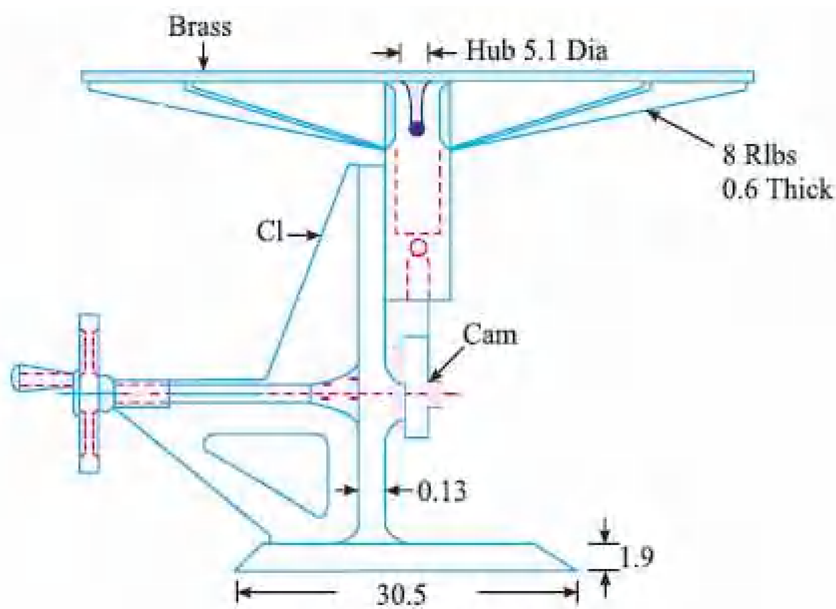
Flow Test

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.

Fig. 6.5 shows the details of apparatus used. It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter, upper surface 17 cm. in diameter, and height of the cone is 12 cm.



Mould For Flow Test



All dimensions in Centimetres

The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After

the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

$$\text{Flow, per cent} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

The value could range anything from 0 to 150 per cent.

A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

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. The disadvantages are that it requires a large sample of concrete and it cannot be used when the concrete is placed in thin section. The minimum

depth of concrete must be at least 20cm and the minimum distance from the centre of the ball to nearest edge of the concrete 23cm

The surface of the concrete is struck off level, avoiding excess working the ball is lowered gradually on the surface of the concrete. The depth of penetration is read immediately on the stem to the nearest 6mm. The test can be performed in about 15 seconds and it gives much more consistent results than slump tests.

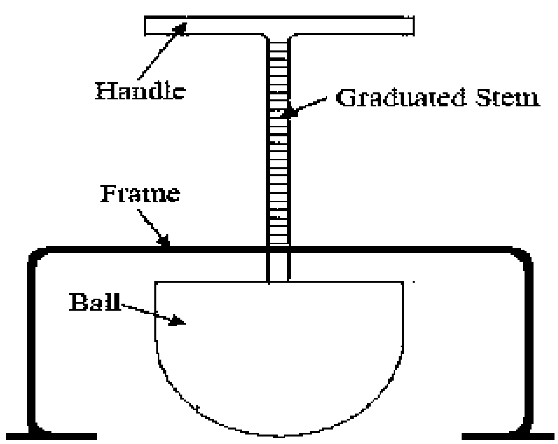
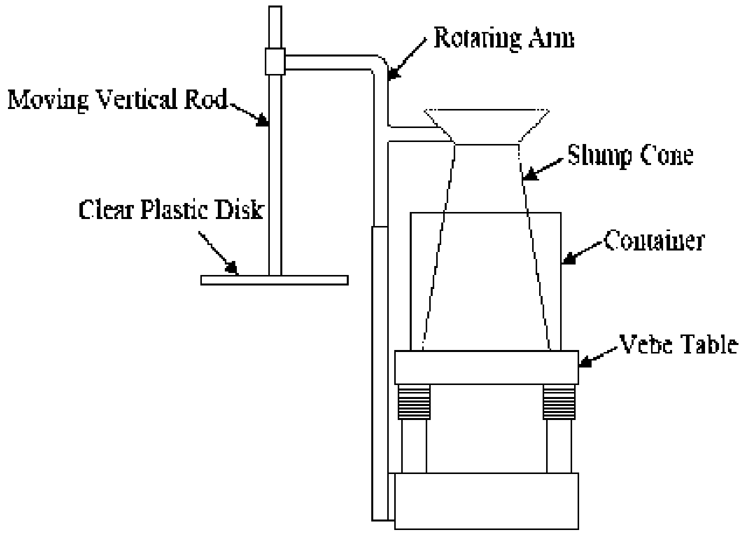


Figure 6: Kelly Ball Test Apparatus

Vee Bee Consistometer Test

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod.



Vebe Consistometer

Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer. The glass disc attached to the swivel 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 concrte assumes a cylindrical shape. This can be judged by observing the glass disccfrom the top for disappearance of tansparency.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 cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by slump test.

Seggregation

A good concrete is one in which all the ingredients are properly distributed to make a homogenous mixture. But in some concrete mixes constituents of concrete exhibits a tendency of separation from rest of the ingredients. Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in hardened concrete. So segregation can be defined as the separation of the constituent materials of concrete.

There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart.

Types

3 types

(i) Coarse aggregate separating out or settling down from the rest of the matrix

(ii)Paste or matrix separating away from coarse aggregate

(iii)Water separating out from the rest of the material

Reasons

Badly proportioned mix where sufficient matrix is not there to bind and contain the aggregate

Insufficiently mixed concrete with excess water content

Dropping of concrete from heights as in the case of placing concrete in column concreting

When concrete is discharged from a badly designed mixer. or from a mixer with worn out blades, concrete shows a tendency for segregation.

Conveyance of concrete by conveyor belts. wheel barrow. long distance haul by dumper. long lift by skip and hoist are the other situations promoting segregation of concrete.

Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. It too wet a mix is excessively vibrated, it is likely that the concrete gets segregated. It should also be remembered that vibration is continued just for required time for optimim results. If the vibration is continued for a long time, particularly, in too wet a mix, it is likely to result in segregation of concrete due to settlement of coarse aggregate in matrix.

In the recent time we use concrete with very high slump particularly in RMC. The slump value required at the batching point may be in the order of 150 mm and at the pumping point the slump may be around 100 mm. At both these points cubes are cast. One has to take care to compact the cube mould with these high slump concrete. If sufficient care and understanding of concrete is not exercised, the concrete in the cube mould may get segregated and show low strength. Similarly care must be taken in the compaction of such concrete in actual structures to avoid segregation.

While finishing concrete floors or pavement, with a view to achieve a smooth surface, masons are likely to work too much with the trowel, float or tamping rule immediately on placing concrete. This immediate working on the concrete on placing, without any time interval, is likely to press the coarse aggregate down, which results in the movement of excess of matrix or paste to the surface. Segragation caused on this account, impairs the homogeneity and serviceability of concrete. The excess mortar at the top causes plastic shrinkage cracks.

Remedies

At any stage, if segregation is observed, remixing for a short time would make the concrete again homogeneous. As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air-entraining agent appreciably reduces segregation.

Measurement

Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test or the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

Bleeding

Bleeding is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding.

Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and floats, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as "Laitance".

Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement.

Remedies

Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse.

use of air-entraining agent is very effective in reducing the bleeding.

bleeding can be reduced by the use of finer cement or cement with low alkali content.

The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its role in providing workability, from the body of concrete by way of bleeding will do good to the concrete. Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, that causes undue harm to the concrete. Controlled revibration may be adopted to overcome the bad effect of bleeding.

Process of Manufacture of Concrete

The various stages of manufacture of concrete are:

a) Batching

b) Mixing

c) Transporting

d) Placing

e) Compacting

f) Curing

g) Finishing.

(a) Batching

The measurement of materials for making concrete is known as batching. There are two methods of batching:

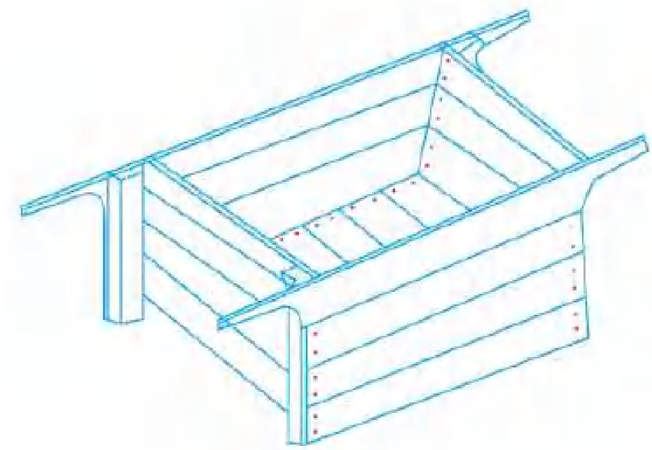
(i) Volume batching

(ii) Weigh batching

Volume batching

Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume.

Cement is always measured by weight it is never measured in volume. Generally for each batch mix, one bag of cement is used. The volume of one bag of cement is taken as thirty five (35) litres. Gauge boxes are used for measuring the fine and Coarse aggregates. The typical sketch of a guage box is shown in Figure. The volume of the box is made equal to the volume of one bag of cement i.e, 35 litres or multiple thereof. The gauge boxes aremade comparatively deeper withnarrow surface rather thanshallow with wider surface tofacilitate easy estimation oftop level. Sometimes bottomless gauge-boxes are used. This should be avoided. Correction to the effect of bulking should be made to cater for bulking of fine aggregate, when the fine aggregate is moist and volume batching is adopted.



Gauge boxes are generally called farmas. They can be made of timber or steel plates. Often in India volume batching is adopted even for large concretingoperations.

Volume of Various gauge boxes

Item	Width cm	Height cm	Depth cm	Volume litres	Quantity number
A	33.3	30	20	20	1
B	33.3	30	25	25	2
C	33.3	30	30	30	2
D	33.3	30	35	35	2
E	33.3	30	40	40	2
F	33.3	30	45	45	2
G	33.3	30	50	50	1

Weigh Batching

Strictly speaking, weigh batching is the correct method of measuringthe materials. For important concrete, invariably, weigh batching system should be adopted. Use of weight system in batching, facilitates accuracy, flexibility and simplicity. Different types of weigh batchers are available.

Mixing

Thorough mixing at the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform colour and consistency. There are two methods adopted for mixing concrete:

(i) Hand mixing

(ii) Machine mixing

Hand Mixing

Hand mixing is practiced for small scale unimportant concrete works. As the mixing cannot be thorough and efficient it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method. Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured Quantity of coarse aggregate and fine aggregate in alternate layers. Pour the cement on the top of it and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved This uniform mixture is spread out in thickness of about 20 cm. Water is taken in a water-can filled with a rose-head and sprinkled over the mixture and simultaneously turned over. This operation is continued till such time a good uniform, homogeneous concrete is obtained it is of particular importance to see that the water is not poured but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the Just required consistency. At that stage, even a small quantity of water makes difference

Machine Mixing

Mixing of concrete is almost invariably carried out by machine for reinforced concrete work and for medium or large scale mass concrete work. Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.

Many types of mixers are available for mixing concrete. They can be classified as

(i) Batch mixers

(ii) Continuous mixers

Batch mixers produce concrete batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working. In this, materials are fed continuously by screw feeders and the materials are continuously mixed and continuously discharged. This type or mixers are used in large works such as dams. In normal concrete work, it is the batch mixers that are used.

Batch mixer may be of pan type or drum type.

As per I.S. 1791–1985, concrete mixers are designated by a number representing itsnominal mixed batch capacity in litres. The following are the standardized sizes of three types:

a. Tilting: 85 T, 100 T, 140 T, 200 T

b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT

c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

The letters T, NT, R denote tilting,

The drum type may be further classified as tilting, non-tilting, reversing or forced action types

Transporting Concrete

Concrete can be transported by a variety of methods and equipment. The precaution to be taken while transporting concrete is that the homogeneity obtained at the time of mixing should be maintained while being transported to the final place of deposition. The methods adopted for transportation of concrete are:

a) Mortar Pan

b) Wheel Barrow, Hand Cart

c) Crane, Bucket and Rope way

(d Truck Mixer and Dumpers

e) Belt Conveyors

f) Chute

g) Skip and Hoist

h) Tansit Mixer

i)Pump and Pipe Line

j) Helicopter

Mortar Pan.

Use of mortar pan for transportation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case concrete is carried in small quantities. While this method nullifies the segregation to some extent particularly in thick members, it suffers from the disadvantage that this method exposes greater surface area of concrete for drying conditions. These results in greater loss of water, particularly, in hot weather concreting and under conditions of low humidity. It is to be noted that the mortar pans must be wetted to start with and it must be kept clean during the entire operation of concreting. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulty

Wheel Barrow

Wheel barrows are normally used for transporting concrete to be placed at ground level. This method is employed for hauling concrete for comparatively longer distance as in the case of concrete road construction. lf concrete is conveyed by wheel barrow over a long distance. on rough ground. it is likely that the concrete gets segregated due to vibration. The coarse aggregates settle down to the bottom and matrix moves to the top surface. To avoid this situation, sometimes, wheel barrows are provided with pneumatic wheel to reduce vibration. A wooden plank road is also provided to reduce vibration and hence segregation.

Crane, bucket and Ropeway

A crane and bucket is one of the right equipment for transporting concrete above ground level. Crane can handle concrete in high rise construction projects and are becoming familiar sites in big cities. Cranes are fast and versatile to move concrete horizontally as well as vertically along the boom and allows the placement of concrete at the exact point. Cranes carry skips or buckets containing concrete. Skips have discharge door at the bottom, whereas buckets are tilted for emptying. For a medium scale job the bucket capacity may be 0.5 m^3

Rope way and bucket of various sizes are used for transporting concrete to a place, where simple method of transporting concrete is found not feasible. For the concrete works in a valley or the construction work of a pier in the river or for dam construction this method of transporting by rope way and bucket is adopted. The mixing of concrete is done on the bank or abutment at a convenient place and the bucket is brought by a pulley or some other arrangement. it is lined up and then taken away to any point that is required. The vertical movement of the bucket is also controlled by another set of pullies. Sometimes, cable and car arrangement is also made for controlling the movement of the bucket This is one of the methods generally adopted for concreting dam work or bridge work Since the Size of the bucket is considerably large and concrete is not exposed to sun and wind there would not be much change in the state of concrete or workability.

For discharging the concrete, the bucket may be tilted or sometimes, the concrete is made to discharge with the help of a hinged bottom. Discharge of concrete may also be through a gate system operated by compressed air. The operation of controlling the gate ml be done manually or mechanically. It should be practised that concrete is discharged from the smallest height possible and should not be made to freely fall from great height.

Truck Mixer and Dumper

For large concrete works particularly for concrete to be placed at ground level, trucks and dumpers or ordinary open steel-body tipping lorries can be used. As they can travel to any part of the work, they have much advantage over the jubilee wagons, which require rail tracks. Dumpers are of usually 2 to 3 cubic metre capacity, whereas the capacity of truck may be 4 cubic metre or more. Before loading with the concrete, the inside of the body should be just wetted with water. Tarpaulins or other covers may be provided to cover the wet concrete during transit to prevent evaporation. When the haul is long, it is advisable to use agitators which prevent segregation and stiffening. The agitators help the mixing process at a slow speed.

For road construction using Slip Form Paver large quantity of concrete is required to be supplied continuously. A number of dumpers of 6 m^3 capacity are employed to supply concrete. Small dumper called Tough Riders is used for factory floor construction.

Belt Conveyors

Belt conveyors have very limited applications in concrete construction. The principal objection is the tendency of the concrete to segregate on steep inclines, at transfer points or change of direction and at the points where the belt passes over the rollers. Another disadvantage is that the concrete is exposed over long stretches which causes drying and stiffening particularly, in hot, dry and windy weather. Segregation also takes place due to the vibration of rubber belt. It is necessary that the concrete should be remixed at the end of delivery before placing on the final position.

Modern Belt Conveyors can have adjustable reach, travelling diverter and variable speed both forward and reverse. Conveyors can place large volumes of concrete quickly where access is limited. There are portable belt conveyors used for short distances or lifts. The end discharge arrangements must be such as to prevent segregation and remove all the mortar on the return of belt in adverse weather conditions (hot and windy) long reaches of belt must be covered.

Chute

Chutes are generally provided for transporting concrete from ground level to a lower level. The sections of chute should be made of or lined with metal and all runs shall have approximately the same slope, not flatter than 1 vertical to 2 1/2 horizontal. The layout is made in such a way that the concrete will slide evenly in a compact mass without any separation or segregation. The required consistency of the concrete should not be changed in order to facilitate chuting. If it becomes necessary to change the consistency the concrete mix will be completely redesigned.

This is not a good method of transporting concrete. However, it is adopted, when movement of labour cannot be allowed due to lack of space or for fear of disturbance to reinforcement or other arrangements already incorporated. [Electrical conduits or switch boards etc.)

Skip and Hoist

This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging and human ladder for transporting concrete is not normally possible for more than 3 or 4 storeyed building constructions. For laying concrete in taller structures, chain hoist or platform host or sklp hoist is adopted

At the ground level, mixer directly feeds the skip and the skip travels up over rails upto the level where concrete is required. At that point, the skip discharges the concrete automatically or on manual operation. The quality of concrete i.e. the freedom from segregation will depend upon the extent of travel and rolling over the rails. If the concrete has travelled a considerable height, it is necessary that concrete on discharge is required to be turned over before being placed finally

Pump and Pipe-line method

It is the most sofisticated method particularly suitable for limited space or when a large quantity of concrete is to be poured without cold joints. Pumping of concrete can be done @ 8 to 70 cum per hour up to a horizontal distance of 300 m and vertical distance of 90 m. Pipe dia is generally 8-20 cm and it is made of steel, plastic or aluminium. The workability for pumped concrete should have a minimum of 40-100 mm of slump or 0.90-0.95 CF. At delivery point, the workability may be reduced by 25% due to compaction and this factor should be kept in mind while designing the mix.

At the end of day's work, the pipe should be cleaned by passing a special ball called 'go devil' forcing through the pipe by air pressure.

Placing Concrete

It is not enough that a concrete mix correctly designed, batched, mixed and transported, it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results. The precautions to be taken and methods adopted while placing concrete in the under-mentioned situations will be discussed.

(a) Placing of concrete within earth mould, (example: Foundation concrete for a wall or column}

(b) Placing concrete within large earth mould or timber plank formwork. (Example: Road slab and Airfield slab)

(c) Placing concrete in layers within timber or steel shutters. (Examples: Mass concrete in dam construction or construction of concrete abutment or pier).

(d) Placing concrete within usual from work. (Example: Columns, beams and floors}.

(e)Placing concrete under water

Concrete is invariably laid as foundation bed below the walls or columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed. Any root of trees passing through the foundation must be cut, charred or tarred effectively to prevent its further growth and piercing the concrete at a later date. The surface of the earth, if dry, must be just made damp so that the earth does not absorb water from concrete. On the other hand if the foundation bed is too wet and rain-soaked, the water and slush must be removed completely to expose firm bed before placing concrete. If there is any seepage of water taking place into the foundation trench, effective method for diverting the flow of water must be adopted before concrete is placed in the trench or pit.

For the construction of road slabs, airfield slabs and ground floor slabs in buildings, concrete is placed in bays. The ground surface on which the concrete is placed must be free from loose earth, pool of water and other organic matters like grass, roots, leaves etc. The earth must be properly compacted and made sufficiently damp to prevent the absorption of water from concrete. If this is not done, the bottom portion of concrete is likely to become weak. Sometimes, to prevent absorption of moisture from concrete, by the large surface of earth, in case of thin road slabs, use of polyethylene film is used in between concrete and ground. Concrete is laid in alternative bays giving enough scope for the concrete to undergo sufficient shrinkage. Provisions for contraction joints and dummy joints are given. It must be remembered that the concrete must be dumped and not poured. It is also to be ensured that concrete must be placed in just required thickness. The practice of placing concrete in a heap at one place and then dragging it should be avoided.

When concrete is laid in great thickness, as in the case of concrete raft for a high rise building or in the construction of concrete pier or abutment or in the construction of mass concrete dam concrete is placed in layers. The thickness of layers depends upon the mode of compaction. In reinforced concrete, it is a good practice to place concrete in layers of about is to

30 cm thick and in mass concrete, the thickness of layer may vary anything between 35 to 45 cm. Several such layers may be placed in succession to form one lift, provided they follow one another quickly enough to avoid cold joints. The thickness of layer is limited by the method of compaction and size and frequency of vibrator used.

Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush in case of dam, even sand blasting is also adopted. The old surface is sometimes hacked and made rough by removing all the laitance and loose material. The surface is wetted. Sometimes, neat cement slurry or a very thin layer of rich mortar with fine sand is dashed against the old surface and then the fresh concrete is placed. The whole operation must be progressed and arranged in such a way that cold joints are avoided as far as possible. When concrete is laid in layers, it is better to leave the top of the layer rough, so that the succeeding layer can have a good bond with the previous layer. Where the concrete is subjected to horizontal thrust bond bars, bond rails or bond stones are provided to obtain a good bond between the successive layers. Of course, such arrangements are required for placing mass concrete in layers but not for reinforced concrete

Certain good rules should be observed while placing concrete within the formwork as in the case of beams and columns. Firstly, it must are checked that the reinforcement is correctly tied placed and is having appropriate cover. The joints between planks, plywoods or sheets must be properly and effectively plugged so that matrix will not escape when the concrete is vibrated. The inside of the formwork should be applied with mould releasing agents for easy stripping. Such purposes made mould releasing agents are separately available for steel or timber shuttering. The reinforcement should be clean and free from oil. Where reinforcement is placed in a congested manner the concrete must be placed very carefully, in small quantity at a time so that it does not block the entry of subsequent concrete. The above situation often takes place in heavily reinforced concrete columns with close lateral ties at the junction of column and beam and in deep beams. Generally, difficulties are experienced for placing concrete in the column. Often concrete is required to be poured from a greater height. When the concrete is poured from a height against reinforcement and lateral ties, it is likely to segregate or block the space to prevent further entry of concrete. To avoid this concrete is directed by tremie, drop chute or by any other means to direct the concrete within the reinforcement and ties. Sometimes, when the formwork is too narrow or reinforcement is too congested to allow the use of tremie or drop chute, a small opening in one of the sides is made and the concrete is introduced from this Opening instead of pouring from the top it is advisable that care must be taken at the stage of detailing of reinforcement for the difficulty in pouring concrete. In long span bridges the depth of prestressed concrete girders may be of the order of even 4 -5 meters involving congested reinforcement. In such situations planning for placing concrete in one operation requires serious considerations on the part of designer.

Underwater Concreting

Concrete is often required to be placed underwater or in a trench filled with the bentonite Slurry. In such cases, use of bottom dump bucket or tremie pipe is made use of. In the bottom dump bucket concrete is taken through the water in a water-tight box or bucket and on reaching the final place of deposition the bottom is made to open by some mechanism and the whole concrete is dumped slowly. This method will not give a satisfactory result as certain amount of washing away of cement is bound to occur.

In some situations, dry or semi-dry mixture of cement, fine and coarse aggregate are filled in cement bags and such bagged concrete is deposited on the bed below the water. This method also does not give satisfactory concrete, as the concrete mass will be full of voids interspersed with the putricible gunny bags. The satisfactory method of placing concrete under water is by the use of tremie pipe.

The word ”tremie“ is derived from the french word hopper.

A tremie pipe is a pipe having a diameter of about 20 cm capable of easy coupling for increase or decrease of length. A funnel is fitted to the top end to facilitate pouring of concrete. The bottom end is closed with a plug or thick polyethylene sheet or such other material and taken below the water and made to rest at the point where the concrete is going to be placed. Since the end is blocked, no water will have entered the pipe. The concrete having a very high slump of about l5 to 20 cm is poured into the funnel. When the whole length of pipe is filled up with the concrete, the tremie pipe is lifted up and a slight jerk is given bya winch and pully arrangement. When the pipe is raised and given a jerk, due to the weight of concrete, the bottom plug falls and the concrete gets discharged. Particular care must be taken at this stage to see that the end of the tremie pipe remains inside the concrete, so that no water enters into the pipe from the bottom. In other words, the tremie pipe remains plugged at the lower end by concrete. Again concrete is poured over the funnel and when the whole length of the tremie pipe is tilled with concrete, the pipe is again slightly lifted and given slight jerk. Care is taken all the time to keep the lower end of the tremie pipe well embedded in the wet concrete. The concrete in the tremie pipe gets discharged. In this way, concrete work is progressed without stopping till the concrete level comes above the water level.

Fig. shows the underwater concreting by tremie.

This method if executed properly has the advantage that the concrete does not get affected by water except the top layer. The top layer is scrubbed 1 or cut off to remove the affected concrete at the end of the whole operation

During the course of concreting, no pumping of water should be permitted. If simultaneous pumping is done, it may suck the cement particles. Under water concreting need not be compacted, as concrete gets automatically compacted by the hydrostatic pressure of water. Secondly, the concrete is of such consistency that it does not normally require compaction. One of the disadvantages of under water concreting in this method is that a high water/cement ratio is required for high consistency which reduces the strength of concrete. But at present, with the use of superplasticizer it is not a constraint. A concrete with as low a w/c ratio as 0.3 or even less can be placed by tremie method.

Another method, not so commonly employed to place concrete below water is the grouting process of prepacked aggregate. Coarse aggregate is dumped to assume full dimension of the concrete mass. Cement mortar grout is injected through pipes, which extend up to the bottom of the aggregate bed. The pipes are slowly withdrawn. as the grouting Progresses. The grout forces the water out from the interstices and occupies the space. For plugging the well foundation this method is often adopted.

Concrete also can be placed under water by the use of pipes and concrete pumps. The Pipeline is plugged at one end and lowered until it rests at the bottom. Pumping is then started. When the pipe is completely filled, the plug is forced out, the concrete surrounding the lower end of the pipe seals the pipe. The pumping is done against the pressure of the plug at the lower end. When the pumping effort required is too great to overcome the pressure, the pipe is withdrawn and the operation is repeated. This process is repeated until concrete reaches the revel above water.

Compaction of Concrete

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of mixing, transporting and placing of concrete air is likely to get entrapped in the concrete. The lower the workability, higher is the amount of air entrapped. In other words, stiff concrete mix has high percentage of entrapped air and, therefore, would need higher compacting efforts than high workable mixes.

The following methods are adopted for compacting the concrete:

(a) Hand Compaction

(i) Rodding

(ii) Ramming

(iii) Tamping

(b)Compaction by Vibration

(i)Internal vibrator (Needle vibrator) .

(ii) Formwork vibrator (External vibrator)

(iv) Table vibrator

(v) Platform vibrator

(vi) Surface vibrator (Screed vibrator)

(vii) Vibratory Roller.

(c)Compaction by Pressure and Jolting

(d) Compaction by Spinning.

Hand Compaction

Hand compaction of concrete is adopted in case of unimportant concrete work of small magnitude. Sometimes, this method is also applied in such situation where a large quantity of reinforcement is used, which cannot be normally compacted by mechanical means. Hand compaction consists of rodding, ramming or tamping. When hand compaction is adopted, the consistency of concrete is maintained at a higher level. The thickness of the layer of concrete is limited to about 15 to 20 cm.

Rodding is nothing but poking the concrete with about 2 metre long, 16 mm diameter rod to pack the concrete between the reinforcement and sharp corners and edges Rodding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes instead of iron rod, bamboos or cane is also used for rodding purpose.

Ramming should be done with care. Light ramming can be permitted in unreinforced foundation concrete or in ground floor construction. Ramming should not be permitted in case of reinforced concrete or in the upper floor construction, where concrete is placed in the formwork supported on struts. If ramming is adopted in the above case the position of the reinforcement may be disturbed or the formwork may fail, particularly, if steel rammer is used.

Tamping is one of the usual methods adopted in compacting roof or floor slab or road pavements where the thickness of concrete is comparatively less and the surface to be finished smooth and level. Tamping consists of beating the top surface by wooden cross beam of section about 10 x 10 cm. Since the tamping bar is sufficiently long it not only compacts, but also levels the top surface across the entire width.

Compaction by Vibration

It is pointed out that the compaction by hand if properly carried out on concrete with sufficient workability, gives satisfactory results but the strength of the hand compacted concrete will be necessarily low because of higher water cement ratio required for full compaction. Where high strength is required, it is necessary that stiff concrete, with low water/cement ratio be used. To compact such concrete, mechanically operated vibratory equipment must be used. The vibrated concrete with low water/cement ratio will have many advantages over the hand compacted concrete with higher water/cement ratio.

The modern high frequency vibrators make it possible to place economically concrete which is impracticable to place by hand. A concrete with about 4 cm slump can be placed and compacted fully in a closely spaced reinforced concrete work, whereas, for hand compaction, much higher consistency say about 12 cm slump may be required.

Internal Vibrator

Of all the vibrators, the internal vibrator is most commonly used. This is also called “Needle Vibrator”, “Immersion Vibrator”, or “Poker Vibrator”. This essentially consists of a power unit, a flexible shaft and a needle. The power unit may be electrically driven or operated by petrol engine or air compressor. The vibrations are caused by eccentric weights attached to the shaft or the motor or to the rotor of a vibrating element Electromagnet, pulsating equipment is also available. The frequency of vibration varies upto 12,000 cycles of vibration per minute. The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. The bigger needle is used in the construction of mass concrete dam. Sometimes, arrangements are available such that the needle can be replaced by a blade of approximately the same length. This blade facilitates vibration of members, where, due to the congested reinforcement, the needle would not go in, but this blade can effectively vibrate. They are portable and can be shifted from place to place very easily during concreting operation. They can also be used in difficult positions and situations.

Formwork Vibrator [External Vibrator)

Formwork vibrators are used for concreting columns, thin walls or in the casting of precast units. The machine is clamped on to the external wall surface of the formwork. The vibration is given to the formwork so that the concrete in the vicinity of the shutter gets vibrated. This method of vibrating concrete is particularly useful and adopted where reinforcement, lateral ties and spacers interfere too much with the internal vibrator. Use of formwork vibrator will produce a good finish to the concrete surface. Since the vibration is given to the concrete indirectly through the formwork they consume more power and the efficiency of external vibrator is lower than the efficiency of internal vibrator.

Table Vibrator

This is the special case of formwork vibrator, where the vibrator is clamped to the table or table is mounted on springs which are vibrated transferring the vibration to the table. They are commonly used for vibrating concrete cubes. Any article kept on the table gets vibrated. This is adopted mostly in the laboratories and in making small but precise prefabricated R.C.C. members.

Platform Vibrator

Platform vibrator is nothing but a table vibrator but it is larger in size. This is used in the manufacture of large prefabricated concrete elements such as electric poles, railway sleepers, prefabricated roofing elements etc. Sometimes, the platform vibrator is also coupled with jerking or shock giving arrangements such that a through compaction is given to the concrete.

Surface Vibrator

Surface vibrators are sometimes knows as, “Screed Board Vibrators". A small vibrator placed on the screed board gives an effective method of compacting and levelling of thin concrete members such as floor slabs, roof slabs and road surface Mostly, floor slabs and roof slabs are so thin that internal Vibrator or any other type of vibrator cannot be easily employed. In such cases, surface vibrator can be effectively used. In general, surface vibrators are not effective beyond about 15 cm. In the modern construction practices like vaccum dewatering technique, or slip-form paving technique, the use of screed board vibrator are common feature. In the above situations double beam screed board vibrators are often used.

Compaction by Pressure and Jolting

This is one of the effective methods of compacting very dry concrete. This method is often used for compacting hollow blocks, cavity blocks and solid concrete blocks. The stiff concrete is vibrated, pressed and also given jolts. With the combined action of the Jolts vibrations and pressure, the stiff concrete gets compacted to a dense form to give good strength and volume stability. By employing great pressure, a concrete of very low water cement ratio can be compacted to yield very high strength.

Compaction by Spinning

Spinning is one of the recent methods of compaction of concrete. This method of compaction is adopted for the fabrication of concrete pipes. The plastic concrete when spun at a very high speed, gets well compacted by centrifugal force. Patented products Such a ”Hume Pipes", “spun pipes" are compacted by spinning process

Vibratory Roller

One or the recent developments of compacting very dry and lean concrete is the use of Vibratory Roller. Such concrete is known as Roller Compacted Concrete. This method of concrete construction originated from Japan and spread to USA and other countries mainly for the construction of dams and pavements Heavy roller which vibrates while rolling is used for the compaction of dry lean concrete.

CURING OF CONCRETE

Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of course, the rate of hydration is fast to start with but continues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23 for hydration and a water/cement ratio of 0.15 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0:38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container as water cement ratio of 0.38 would satisfy the requirement of water for hydration and at the same time no capillary cavities would be left. However, it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

In the field and in actual work, it is a different story. Even though a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for directive hydration to take place particularly in the top layer. If the hydration is to continue unbated, extra water must be added to replenish the loss of water on account of absorption and evaporation. Alternatively, some measures must be taken by way of provision of impervious covering or application of curing compounds to prevent the loss of water from the surface of the concrete. Therefore, the curing can be considered as creation of a favorable environment during the early period for uninterrupted hydration. The desirable conditions are a suitable temperature and ample moisture

Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue, More elaborately, it can be described as the process of maintaining a satisfactory moisture content and a favourable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet therequirement of service.

Curing is being given a place of increasing importance as the demand for high quality concrete is increasing. It has been recognized that the quality of concrete shows all round improvement with efficient uninterrupted curing. If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss. An efficient curing in the early period of hydration can be compared to a good and wholesome feeding given to a new born baby.

A concrete laid in the afternoon of a hot summer day in a dry climatic region, is apt to dry out quickly. The surface layer of concrete exposed to acute drying condition, with the combined effect of hot sun and drying wind is likely to be made up of poorly hydrated cement with inferior gel structure which does not give the desirable bond and strength characteristics. In addition, the top surface, particularly that of road or floor pavement is also subjected to a large magnitude of plastic shrinkage stresses. The dried concrete naturally being weak, cannot withstand these stresses with the result that innumerable cracks develop at the surface. The top surface of such hardened concrete on account of poor gel structure, suffers from lack of wearing quality and abrasion resistance. Therefore, such surfaces create mud in the rainy season and dust in summer.

The quick surface drying of concrete results in the movement of moisture from the interior to the surface. This steep moisture gradient cause high internal stresses which are also responsible for internal micro cracks in the semi-plastic concrete.

Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough watercuring.

Curing methods may be divided broadly into four categories:

(a)Water Curing

(b) Membrane curing

(c) Application of heat

(d) Miscellaneous

Water Curing

Water curing can be done in the following ways;

(a)Immersion

(b)Ponding

(c) Spraying or Fogging

(d) Wet covering

The precast concrete items are normally immersed in curing tanks for certain duration.

Pavement slabs, roof stab etc. are covered underwater by making small ponds. Ponding of Water over the Concrete Surface after it has set is the most common method of curing the concrete slab or pavements. It consists of storing the water to a depth of 50 mm on the surface by constructing small puddle clay bunds all around.

Covering the Concrete with Wet Straw or Damp Earth is another method. In this method the damp earth or sand in layers of 50 mm height are spread over the surface of concrete pavements. The material is kept moist by periodical sprinkling of water.

The concrete is covered with burlap (coarse jute or hemp) as soon as possible after placing, and the material is kept continuously moist for the curing period. The covering material can be used a number of times and, therefore, tends to be economical

Vertical retaining wall or plastered surfaces or concrete columns etc. are cured by spraying water. In some cases, wet coverings such as wet gunny bags, hessian cloth, jute matting, straw etc., are wrapped to vertical surface for keeping the concrete wet.

Membrane Curing

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. It has been pointed out earlier that curing does not mean only application of water, it means also creation, of conditions for promotion of uninterrupted and progressive hydration. It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane which will effectively seal off the evaporation of water from concrete. It is found that the application of membrane or a sealing compound, after a short spell of water curing for one or two days is sometimes beneficial.

Sometimes, concrete is placed in some inaccessible, difficult or far off places. The curing of such concrete cannot be properly supervised. The curing is entirely left to the workmen who do not quite understand the importance of regular uninterrupted curing. In such cases, it is much safer to adopt membrane curing rather than to leave the responsibility of curing to workers.

Large number of sealing compounds have been developed in recent years. The idea is to obtain a continuous seal over the concrete surface by means of a firm impervious film to prevent moisture in concrete from escaping by evaporation. Sometimes, such films have been used at the interface of the ground and concrete to prevent the absorption of water by the ground from the concrete. Some of the materials that can be used for this purpose are bituminous compounds, polythene or polyester film, waterproof paper, rubber compounds etc.

Application of heat

The development of strength of concrete is a function of not only time but also that of temperature. When concrete is subjected to higher temperature it accelerates the hydration process resulting in faster development of strength Concrete cannot be subjected to dry heat to accelerate the hydration process as the presence of moisture is also an essential requisite. Therefore subjecting the concrete to higher temperature and maintaining the required wetness can be achieved by subjecting the concrete to steam curing.

A faster attainment of strength will contribute to many other advantages mentioned below

a) Concrete is vulnerable to damage only for short time.

b) Concrete member can be handled very quickly

c) Less Space will be sufficient in the casting yard

(d) A smaller curing tank will be sufficient

e) A higher outturn is possible for a given capital outlay

f) The work can be put on to service at a much early time,

g) A fewer number of formwork will be sufficient or alternatively with the given number of formwork more outturn will be achieved,

(h) Prestressing bed can be released early for further casting.

From the above mentioned advantages it can be seen that steam curing will give not only economic advantages but also technical advantages in the matter of prefabrication of concrete elements. The exposure of concrete to higher temperature is done in the following manner:

a) Steam curing at ordinary pressure.

b)Steam curing at high pressure.

c) Curing by Infra-red radiation.

d)Electrical curing.

Steam curing at ordinary pressure

This method of cuing is often adopted for prefabricated concrete elements. Application of steam curing to in situ construction will be a little difficult task. However, at some places it has been tried for in situ construction by forming a steam jacket with the help of tarpaulin or thick polyethylene sheets. But this method of application of steam for in situ work to be wasteful and the intended rate of development of strength and benefit are not really achieved

Steam curing at ordinary pressure is applied mostly on prefabricated elements stored in a chamber. The chamber should be big enough to hold a day’s production. The door is closed and steam is applied. The steam may be applied either continuously or intermittently. An accelerated hydration takes place at this higher temperature and the concrete products attain the 28 days strength of normal concrete in about 3 days

In large prefabricated factories they have tunnel curing arrangements. The tunnel of sufficient length and size is maintained at different temperature starting from a low temperature in the beginning of the tunnel to a maximum temperature of about 90°C at the end of the tunnel. The concrete products mounted on trollies move in a very slow Speed subjecting the concrete products progressively to higher and higher temperature. Alternatively the trollies are kept stationary at different zones for some period and finally come out of tunnel.

High Pressure Steam Curing

In the steam curing at atmospheric pressure, the temperature of the steam is naturally below 100°C. The steam will get converted into water, thus it can be called in a way, as hot water curing. This is done in an open atmosphere.

The high pressure steam curing is something different from ordinary steam curing, in that the Curing is carried out in a closed chamber. The superheated steam at high pressure and high temperature is applied on the concrete. This process is also called "Autoclaving". The autoclaving process is practiced in curing precast concrete product in the factory, particularly, for the lightweight concrete products. In India, this high pressure steam curing is practised in the manufacture of cellular concrete products, such as Siporex, Celcrete etc. The following advantages are derived from high pressure steam curing process:

a) High pressure steam cured concrete develops in one day, or less the strength as much as the 28 days strength of normally cured concrete. The strength developed does not show retrogression

b) High pressure steam cured concrete exhibits higher resistance to sulphate attack, freezing and thawing action and chemical action. It also shows less efflorescence.

c) High pressure steam cured concrete exhibits lower drying shrinkage, and moisture movement

In high pressure steam curing, concrete is subjected to a maximum temperature of about 175°C which corresponds to a steam pressure of about 8.5 kg/sq.cm.

Curing by infra-red Radiation

Curing of concrete by Infra-red Radiation has been practised in very cold climatic region in Russia. It is claimed that much more rapid gain of strength can be obtained than with steam curing and that rapid initial temperature does not cause a decrease in the ultimate strength as in the case of steam curing at ordinary pressure. The system is very often adopted for the curing of hollow concrete products. The normal operative temperature is kept at about 90°C.

Electrical Curing

Another method of curing concrete, which is applicable mostly to very cold climatic regions, is the use of electricity. This method is not likely to find much application in ordinary climate owing to economic reasons.

Concrete can be cured electrically by passing an alternating current (Electrolysis trouble will be encountered if direct current is used) through the concrete itself between two electrodes either buried in or applied to the surface of the concrete. Care must be taken to prevent the moisture from going out leaving the concrete completely dry. As this method is not likely to be adopted in this country, for a long time to come, this aspect is not dismissed in detail.

Miscellaneous Methods of Curing

Calcium chloride is used either as a surface coating or as an admixture. It has been used satisfactorily as a curing medium. Both these methods are based on the fact that calcium Chloride being a salt shows affinity for moisture. The salt not only absorbs moisture from atmosphere but also retains it at the surface. This moisture held at the surface prevents the mixing water from evaporation and there by keeps the concrete wet for a long time to promote hydration. .

Formwork prevents escaping of moisture from the concrete, particularly, in thecase of beam and column. Keeping the formwork intact and sealing the joint with wax or any other sealing compound prevents the evaporation of moisture from the concrete. This procedure of promoting hydration can be considered as one or the miscellaneous methods of curing.

ADMIXTURES

Admixtures are ingredients other than water, cement and aggregates added to concrete immediately before or during mixing. An admixture is used to modify one or more properties of ordinary concrete in its fresh or hardened state to make it more suitable for any situation. Admixtures are not substitute for good concreting practice. The use of admixture should offer an improvement not economically attainable by adjusting the proportions of water, cement and aggregates.

The properties commonly modified are rate of hydration or setting times, workability, dispersion and air entrainment.

The important types of admixtures are

- Plasticizers
- Superplasticizers
- Retarders and Retarding Plasticizers
- Accelerators and Accelerating Plasticizers
- Air-entraining Admixtures
- Pozzolanic or Mineral Admixtures
- Damp-proofing and Waterproofing Admixtures
- Gas forming Admixtures
- Air-detraining Admixtures
- Alkali-aggregate Expansion Inhibiting Admixtures
- Workability Admixtures
- Grouting Admixtures
- Corrosion Inhibiting Admixtures
- Bonding Admixtures
- Fungicidal, Germicidal, Insecticidal Admixtures
- Colouring Admixtures

Plasticizers

The organic substances or combinations of organic and inorganic substances, which allow a reduction in water content for the given workability, or give a higher workability at the same water content, are termed as plasticizing admixtures. The advantages are considerable in both cases : in the former, concretes are stronger, and in the latter they are more workable.

The basic products constituting plasticizers are as follows:

(*i*) Anionic surfactants such as lignosulphonates and their modifications and derivatives, salts of sulphonates hydrocarbons.

(*ii*) Nonionic surfactants, such as polyglycol esters, acid of hydroxylated carboxylic acids and their modifications and derivatives.

(*iii*) Other products, such as carbohydrates etc.

Among these, calcium, sodium and ammonium lignosulphonates are the most used. Plasticizers are used in the amount of 0.1% to 0.4% by weight of cement.

A good plasticizer fluidizes the mortar or concrete in a different manner than that of the air-entraining agents. Some of the plasticizers, while improving the workability, entrains air also. As the entrainment of air reduces the mechanical strength, a good plasticizer is one which does not cause air-entrainment in concrete more than 1 or 2%.

Superplasticizers (High Range Water Reducers)

They are chemically different from normal plasticiszers. Use of superplasticizers permit the reduction of water to the extent upto 30 per cent without reducing workability in contrast to the possible reduction up to 15 per cent in case of plasticizers.

The use of superplasticizer is practiced for production of flowing, self levelling, self compacting and for the production of high strength and high performance concrete.

It is the use of superplasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 Mpa or more. It is the use of superplasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

Superplasticizers can produce:

- at the same w/c ratio much more workable concrete than the plain ones,
- for the same workability, it permits the use of lower w/c ratio,
- as a consequence of increased strength with lower w/c ratio, it also permits a reduction of cement content.

The superplasticizers also produce a homogeneous, cohesive concrete generally without any tendency for segregation and bleeding.

Classification of Superplasticizer. Following are a few polymers which are commonly used as base for superplasticizers.

- Sulphonated malanie-formaldehyde condensates (SMF)
- Sulphonated naphthalene-formaldehyde condensates (SNF)
- Modified lignosulphonates (MLS)
- Other types

In addition to the above, in other countries the following new generation superplasticizers are also used.

- Acrylic polymer based (AP)
- Copolymer of carboxylic acrylic acid with acrylic ester (CAE)
- Cross linked acrylic polymer (CLAP)
- Polycarboxylate ester (PC)
- Multicarboxylatethers (MCE)
- Combinations of above.

Out of the above new generation superplasticizers based on carboxylic acrylic ester (CAE) and multicarboxylatether (MCE) are discussed later.

Retarders

A retarder is an admixture that slows down the chemical process of hydration so that concrete remains plastic and workable for a longer time than concrete without the retarder.

Retarders are used to overcome the accelerating effect of high temperature on setting properties of concrete in hot weather concreting. The retarders are used in casting and consolidating large number of pours without the formation of cold joints. They are also used in grouting oil wells. Oil wells are sometimes taken upto a depth of about 6000 meter deep where the temperature may be about 200°C. The annular spacing between the steel tube and the wall of the well will have to be sealed with cement grout. Sometimes at that depth stratified or porous rockstrata may also require to be grouted to prevent the entry of gas or oil into some other strata. For all these works cement grout is required to be in mobile condition for about 3 to 4 hours, even at that high temperature without getting set. Use of retarding agent is often used for such requirements.

Sometimes concrete may have to be placed in difficult conditions and delay may occur in transporting and placing. In ready mixed concrete practices, concrete is manufactured in central batching plant and transported over a long distance to the job sites which may take considerable time. In the above cases the setting of concrete will have to be retarded, so that concrete when finally placed and compacted is in perfect plastic state.

Retarding admixtures are sometimes used to obtain exposed aggregate look in concrete. The retarder sprayed to the surface of the formwork, prevents the hardening of matrix at the interface of concrete and formwork, whereas the rest of the concrete gets hardened. On removing the formwork after one day or so, the unhardened matrix can be just washed off by a jet of water which will expose the aggregates. The above are some of the instances where a retarding agent is used.

Perhaps the most commonly known retarder is calcium sulphate. It is interground to retard the setting of cement. The appropriate amount of gypsum to be used must be determined carefully for the given job. Use of gypsum for the purpose of retarding setting time is only recommended when adequate inspection and control is available, otherwise, addition of excess amount may cause undesirable expansion and indefinite delay in the setting of concrete.

In addition to gypsum there are number of other materials found to be suitable for this purpose. They are: starches, cellulose products, sugars, acids or salts of acids.

Other admixtures which have been successfully used as retarding agents are Ligno sulphonic acids and their salts, hydroxylated carboxylic acids and their salts which in addition to the retarding effect also reduce the quantity of water requirement for a given workability. This also increases 28 days compressive strength by 10 to 20 per cent.

Retarding Plasticizers

It is mentioned earlier that all the plasticizers and superplasticizers by themselves show certain extent of retardation. Many a time this extent of retardation of setting time offered by admixtures will not be sufficient. Instead of adding retarders separately, retarders are mixed with plasticizers or superplasticizers at the time of commercial production. Such commercial brand is known as retarding plasticizers or retarding superplasticizers. ASTM type D is retarding plasticizers and ASTM type G is retarding superplasticizer. In the commercial formulation we have also retarding and slump retaining version.

Retarding plasticizers or superplasticizers are important category of admixtures often used in the Ready mixed concrete industry for the purposes of retaining the slump loss, during high temperature, long transportation, to avoid construction or cold joints, slip form construction and regulation of heat of hydration.

Accelerators

Accelerating admixtures are added to concrete to increase the rate of early strength development in concrete to

- permit earlier removal of formwork;
- reduce the required period of curing;
- advance the time that a structure can be placed in service;
- partially compensate for the retarding effect of low temperature during cold weather concreting;
- in the emergency repair work.

In the past one of the commonly used materials as an accelerator was calcium chloride. But, now a days it is not used. Instead, some of the soluble carbonates, silicates fluosilicates and some of the organic compounds such as triethenolamine are used. Accelerators such as fluosilicates and triethenolamine are comparatively expensive.

Some of the accelerators produced these days are so powerful that it is possible to make the cement set into stone hard in a matter of five minutes are less. With the availability of such powerful accelerator, the under water concreting has become easy. Similarly, the repair work that would be carried out to the waterfront structures in the region of tidal variations has become easy. The use of such powerful accelerators have facilitated, the basement waterproofing operations. In the field of prefabrication also it has become an invaluable material. As these materials could be used up to 10°C, they find an unquestionable use in cold weather concreting.

Accelerating Plasticizers

Certain ingredients are added to accelerate the strength development of concrete to plasticizers or superplasticizers. Such accelerating superplasticizers, when added to concrete result in faster development of strength. The accelerating materials added to plasticizers or superplasticizers are triethenolamine chlorides, calcium nutrite, nitrates and flousilicates etc. The accelerating plasticizers or accelerating superplasticizers manufactured by well known companies are chloride free.

Air-entraining Admixture

Air entrained concrete is made by mixing a small quantity of air entraining agent or by using air entraining cement. These air entraining agents incorporate millions of non-coalescing air bubbles, which will act as flexible ball bearings and will modify the properties of plastic concrete regarding workability, segregation, bleeding and finishing quality of concrete. It also modifies the properties of hardened concrete regarding its resistance to frost action and permeability.

The air voids present in concrete can be brought under two groups:

(*a*) Entrained air (*b*) Entrapped air.

Entrained air is intentionally incorporated, minute spherical bubbles of size ranging from 5 microns to 80 microns distributed evenly in the entire mass of concrete. The entrapped air is the voids present in the concrete due to insufficient compaction. These entrapped air voids may be of any shape and size normally embracing the contour of aggregate surfaces. Their size may range from 10 to 1000 microns or more and they are not uniformly distributed throughout the concrete mass.

Air entraining agents

The following types of air entraining agents are used for making air entrained concrete.

(*a*) Natural wood resins.

(*b*) Animal and vegetable fats and oils, such as tallow, olive oil and their fatty acids such as stearic and oleic acids.

(*c*) Various wetting agents such as alkali salts or sulphated and sulphonated organic compounds.

(*d*) Water soluble soaps of resin acids, and animal and vegetable fatty acids.

(*e*) Miscellaneous materials such as the sodium salts of petroleum sulphonic acids, hydrogen peroxide and aluminium powder, etc.

Factors affecting amount of air entrainment

The manufacture of air entrained concrete is complicated by the fact that the amount of air entrainment in a mix is affected by many factors; the important ones are:

(*a*) The type and quantity of air entraining agent used.

(*b*) Water/cement ratio of the mix.

(*c*) Type and grading of aggregate.

(*d*) Mixing time.

(*e*) The temperature.

(*f*) Type of cement.

(*g*) Influence of compaction.

(*h*) Admixtures other than air entraining agent used..

The Effect of Air Entrainment on the Properties of Concrete

Air entrainment will effect directly the following three properties of concrete:

(*a*) Increased resistance to freezing and thawing.

(*b*) Improvement in workability.

(*c*) Reduction in strength.

Incidentally air entrainment will also effect the properties of concrete in the following ways:

(*a*) Reduces the tendencies of segregation.

(*b*) Reduces the bleeding and laitance.

(*c*) Decreases the permeability.

(*d*) Increases the resistance to chemical attack.

(*e*) Permits reduction in 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.

Pozzolanic or Mineral Admixtures

It has been amply demonstrated that the best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

(*a*) Lower the heat of hydration and thermal shrinkage;

(*b*) Increase the watertightness;

(*c*) Reduce the alkali-aggregate reaction;

(*d*) Improve resistance to attack by sulphate soils and sea water;

(*e*) Improve extensibility;

(*f*) Lower susceptibility to dissolution and leaching;

(*g*) Improve workability;

(*h*) Lower costs.

In addition to these advantages, contrary to the general opinion, good pozzolans will not unduly increase water requirement or drying shrinkage.

Pozzolanic Materials

Pozzolanic materials are siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds, possessing cementitious properties.

It has been shown in Chapter I that on hydration of tri-calcium silicate and di-calcium silicate, calcium hydroxide is formed as one of the products of hydration. This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. The siliceous or aluminous compound in a finely divided form react with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. Generally, amorphous silicate reacts much more rapidly than the crystalline form. It is pointed out that calcium hydroxide, otherwise, a water soluble material is converted into insoluble cementitious material by the reaction of pozzolanic materials.

The reaction can be shown as

$$\text{Pozzolan} + \text{Calcium Hydroxide} + \text{Water} \rightarrow \text{C} - \text{S} - \text{H (Gel)}$$

This reaction is called pozzolanic reaction. The characteristic feature of pozzolanic reaction is firstly slow, with the result that heat of hydration and strength development will be accordingly slow. The reaction involves the consumption of $Ca(OH)_2$ and not production of $Ca(OH)_2$. The reduction of $Ca(OH)_2$ improves the durability of cement paste by making the paste dense and impervious.

Pozzolanic materials can be divided into two groups: natural pozzolana and artificial pozzolana.

Natural Pozzolans

- Clay and Shales
- Opalinc Cherts
- Diatomaceous Earth
- Volcanic Tuffs and Pumicites.

Artificial Pozzolans

- Fly ash
- Blast Furnace Slag
- Silica Fume
- Rice Husk ash
- Metakaoline
- Surkhi.

Other mineral admixtures, like finely ground marble, quartz, granite powder are also used. They neither exhibit the pozzolanic property nor the cementitious properties. They just act as inert filler.

Damp-proofing and Waterproofing Admixture

In practice one of the most important requirements of concrete is that it must be impervious to water under two conditions, firstly, when subjected to pressure of water on one side, secondly, to the absorption of surface water by capillary action.

Waterproofing admixtures may be obtained in powder, paste or liquid form and may consist of pore filling or water repellent materials. The chief materials in the pore filling class are silicate of soda, aluminium and zinc sulphates and aluminium and calcium chloride. These are chemically active pore fillers. In addition they also accelerate the setting time of concrete and thus render the concrete more impervious at early age. The chemically inactive pore filling materials are chalk, fullers earth and talc and these are usually very finely ground. Their chief action is to improve the workability and to facilitate the reduction of water for given workability and to make dense concrete which is basically impervious.

Some materials like soda, potash soaps, calcium soaps, resin, vegetable oils, fats, waxes and coal tar residues are added as water repelling materials in this group of admixtures. In some kind of waterproofing admixtures inorganic salts of fatty acids, usually calcium or ammonium stearate or oleate is added along with lime and calcium chloride. Calcium or ammonium stearate or oleate will mainly act as water repelling material, lime as pore filling material and calcium chloride accelerates the early strength development and helps in efficient curing of concrete all of which contribute towards making impervious concrete.

Some type of waterproofing admixtures may contain butyl stearate, the action of which is similar to soaps, but it does not give frothing action. Butyl stearate is superior to soap as water repellent material in concrete.

Gas Forming Agents

A gas forming agent is a chemical admixture such as aluminium powder. It reacts with the hydroxide produced in the hydration of cement to produce minute bubbles of hydrogen gas throughout the matrix. The extent of foam or gas produced is dependent upon the type and amount of aluminium powder, fineness and chemical composition of cement, temperature and mix proportions. Usually unpolished aluminium powder is preferred. The amount added are usually 0.005 to 0.02 per cent by weight of cement which is about one teaspoonful to a bag of cement. Larger amounts are being used for the production of light weight concrete.

Air-detraining agents

There have been cases where aggregates have released gas into or caused excessive air entrainment, in plastic concrete which made it necessary to use an admixture capable of dissipating the excess of air or other gas. Also it may be required to remove a part of the entrained air from concrete mixture. Compounds such as tributyl phosphate, water-insoluble alcohols and silicones have been proposed for this purpose. However, tributyl phosphate is the most widely used air-detraining agent.

Alkali-aggregate expansion inhibitors

alkali-aggregate reaction can be reduced by the use of pozzolanic admixture.

air entraining admixture reduces the alkali-aggregate reaction slightly. The other admixtures that may be used to reduce the alkali-aggregate reaction are aluminium powder and lithium salts.

Workability Agents

Some admixtures can be used to improve workability. The materials used as workability agents are:

(*a*) finely divided material,

(*b*) plasticizers and superplasticizers,

(*c*) air-entraining agents

The use of finely divided admixture in appropriate quantity improves workability, reduces rate and amount of bleeding, increases the strength of lean concrete and may not increase water requirement and drying shrinkage. Common materials added as workability agents are bentonite clay, diatomaceous earth, fly ash, finely divided silica, hydrated lime and talc.

Use of plasticizers and superplasticizers are one of the most commonly adopted methods for improvement of workability

Grouting Agents

Grouting under different conditions or for different purposes would necessitate different qualities of grout-mixture. Sometimes grout mixtures will be required to set quickly and sometimes grout mixtures will have to be in fluid form over a long period so that they may flow into all cavities and fissures. Sometimes in grout mixtures, a little water is to be used but at the same time it should exhibit good workability to flow into the cracks and fissures. There are many admixtures which will satisfy the requirements of grout mixture. Admixtures used for grouting are:

(*a*) Accelerators

(*b*) Retarders

(*c*) Gas forming agents

(*d*) Workability agents

(*e*) Plasticizers.

Corrosion Inhibiting Agents

sodium benzoate was used as corrosion inhibiting admixture to protect the steel in reinforced concrete. In this process 2 per cent sodium benzoate is used in the mixing water or a 10 per cent benzoate cement slurry is used to paint the reinforcement or both. Sodium benzoate is also an accelerator of compressive strength.

It is found that calcium lignosulphonate decreased the rate of corrosion of steel embedded in the concrete, when the steel reinforcement in concrete is subjected to alternating or direct current.

Sodium nitrate and calcium nitrite have been found to be efficient inhibitors of corrosion of steel in autoclaved products. Two or three per cent sodium nitrate by weight of cement is said to serve the purpose. There are number of commercial admixtures available now to inhibit corrosion. Mc-Corrodur is one such admixture manufactured by Mc-Bauchimie (Ind) Pvt. Ltd.

Bonding Admixture

Bonding admixtures are water emulsions of several organic materials that are mixed with cement or mortar grout for application to an old concrete surface just prior to patching with mortar or concrete. Sometimes they are mixed with the topping or patching material. Their function is to increase the bond strength between the old and new concrete. This procedure is used in patching of eroded or spalled concrete or to add relatively thin layers of resurfacing.

The commonly used bonding admixtures are made from natural rubber, synthetic rubber or from any organic polymers. The polymers include polyvinyl chloride, polyvinyl acetate etc.

Bonding admixtures fall into two general categories, namely, re-emulsifiable types and non-re-emulsifiable types. The latter is better suited for external application since it is resistant to water.

These emulsions are generally added to the mixture in proportions of 5 to 20 per cent by weight of cement.

Fungicidal, Germicidal and Insecticidal Admixtures

It has been suggested that certain materials may either be ground into the cement or added as admixtures to impart fungicidal, germicidal or insecticidal properties to hardened cement pastes, mortars or concretes. These materials include polyhalogenated phenols, dieldren emulsion or copper compounds.

Colouring Agents

Pigments are often added to produce colour in the finished concrete. The requirements of suitable admixtures include (*a*) colour fastness when exposed to sunlight (*b*) chemical stability in the presence of alkalinity produced in the set cement (*c*) no adverse effect on setting time or strength development. Various metallic oxides and mineral pigments are used.

Pigments should preferably be thoroughly mixed or interground with the dry cement. They can also be mixed with dry concrete mixtures before the addition of mixing water.

Miscellaneous Admixtures

There are hundreds of commercial admixtures available in India. They effect more than one property of concrete. Sometimes they are ineffective and do not fulfil the claims of the manufacturers. It is not intended to deal in detail about these commercial admixtures. However, a few of the more important admixtures are briefly described and some of them are just named.

All these commercial admixtures can be roughly brought under two categories (*a*) Damp proofers (*b*) Surface hardeners, though there are other agents which will modify the properties like strength, setting time, workability etc.

Damp Proofers

(*a*) **Accoproof:** It is a white powder to be mixed with concrete at the rate of 1 kg per bag of cement for the purpose of increasing impermeability of concrete structures.

(*b*) **Natson's Cement WaterProofer:** As the name indicates, it is a waterproofing admixture to be admixed at the rate of 1.5 kg per bag of cement.

(*c*) **Trip-L-Seal:** It is a white powder, the addition of which is claimed to decrease permeability of concrete and mortars and produce rapid hardening effect.

(*d*) **Cico:** It is a colourless liquid which when admixed with concrete, possesses the properties of controlling setting time, promoting rapid hardening, increasing strength and rendering the concrete waterproof.

(*e*) **Feb-Mix-Admix:** It is a light yellow coloured liquid claimed to impart waterproofing quality to concrete and increase workability and bond.

(*f*) **Cemet:** It is a waterproofing admixture. The recommended dose is 3 per cent by weight of cement. It is also claimed that its use in concrete will prevent efflorescence and growth of fungi.

In addition to the above the following are some of the commercial waterproofing admixtures:

(*a*) Arzok
(*b*) Bondex
(*c*) Impermo
(*d*) Luna-Ns-1
(*e*) Sigmet
(*f*) Arconate No. 2
(*g*) Swadco No. 1
(*h*) Rela
(*i*) Wet seal
(*j*) Water lock
(*k*) Scott No. 1
(*l*) Hydrofuge
(*m*) Omson's "Watse"

Surface Hardeners

(*a*) **Metal Crete:** Metal crete is a metallic aggregate which is tough, ductile, specially processed, size graded iron particles with or without cement dispersing agent. It is claimed that it gives greater wear resistance, corrosion resistance, non-dusting and non-slipping concrete surface.

(*b*) **Ferrocrete No. 1:** It is a surface hardener and makes the concrete surface compact, dense and homogeneous.

(*c*) **Metal Crete Steel Patch:** It is a surface hardener. When added 20 per cent by weight of cement, it is supposed to increase the compressive strength and abrasion resistance.

(*d*) **Arconate No. 1:** It is a black powder composed of iron filings. It is used as surface hardener in concrete.

In addition to the above, the other admixtures used as surface hardeners are:

(*i*) Ironite; (*ii*) Merconite;

(*iii*) Meta Rock; (*iv*) Purelite.

Another important admixture which has been very popular is "Lisspol N". It is a polyetheoxy surface active agent which improves workability, strength and many other important properties of concrete when used in a very small dose of $\frac{1}{2}$ oz per bag of cement.

The commercial admixtures are not dependable. It has been common experience that many a time when these admixtures are tested in a laboratory the manufacturer's or distributor's claims are not fulfilled. So it will be wrong to have much faiths in these commercial admixtures though some of them give some encouraging results.

MODULE 1

INGREDIENTS OF CEMENT

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

Ingradient	Percent	Range (%)
Lime (CaO)	63	60-67
Silica (SiO_2):	20	17-25
Alumina (Al_20_3)	6	3-8
Iron oxide (Fe_20_3)	3	0.5-6
Magnesia (MgO)	1.5	0.1-4
Alkalies (Na_2O, K_2O)	1	0.4-1.3
Sulphur trioxide (S03)	2	1.3-3

Bouge's Compounds

Basic ingredients of cement when subjected to high clinkering temperature combine with each other to form complex compounds. They are called **Bouge's Compounds**

Bogue's Compounds

Name of Compound	*Formula*	*Abbreviated Formula*
Tricalcium silicate	$3\ CaO.SiO_2$	C_3S
Dicalcium silicate	$2\ CaO.Sio_2$	C_2S
Tricalcium aluminate	$3\ Cao.Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4\ CaO.Al_2O_3.Fe_2O_3$	C_4AF

Calculated compound composition using Bogue's equation per cent	
C_3S	54.1
C_2S	16.6
C_3A	10.8
C_4AF	9.1

In addition to the four major compounds, there are many minor compounds formed in the kiln. The influence of these minor compounds on the properties of cement or hydrated compounds is not significant. Two of the minor oxides namely K_2O and Na_2O referred to as alkali in cement are of some importance.

Tricalcium silicate and dicalcium silicate are the most important compounds responsible for strength. Together they constitute 70 to 80 per cent of cement. The average C_3S content in modern cement is about 45 per cent and that of C_2S is about 25 per cent

Bogue's compounds C_3S, C_2S, C_3A and C_4AF are sometimes called in literature as Alite, Belite, Celite and Felite respectively

Hydration of Cement

Anhydrous cement does not bind fine and coarse aggregate. It acquires adhesiveproperty only when mixed with water. The chemical reactions that take place between cement and water is referred as hydration of cement.

Anhydrous cement compounds when mixed with water react with each other to form hydrated compounds of very low solubility. The hydration of cement can be visualized in two ways. The first is ”through solution“mechanism. In this the cement compounds dissolve to produce a supersaturated solution from which different hydrated products get precipitated. The second possibility isthat water attacks cement compounds in the solid state converting the compounds into hydrated products starting from the surface and proceeding to the interior of the compounds with time. It is probable that both “through solution" and ”solid state” types of mechanism may occur during the course of reactions between cement and water. The former mechanism may predominate in the early stages of hydration in view of large quantities of water being available, and the latter mechanism may operate during the later stages of hydration.

Heat of Hydration

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration.

On mixing cement with water, a rapid heat evolution, lasting a few minutes, occurs. This heat evolution is probably due to the reaction of solution of aluminates and sulphates. This initial heat evolution ceases quickly when the solubility of aluminate is depressed by gypsum. Next heat evolution is on account of formation of ettringite and also may be due to the reaction of C_3S

Different compounds hydrate at different rates and liberate different quantities of heat. Since retarders are added to control the flash setting properties of C_3A, actually the early heat of hydration is mainly contributed from the hydration of C_3S. Fineness of cement also influences the rate of development of heat. The total quantity of heat generated in the complete hydration will depend upon the relative quantities of the major compounds present in a cement.

Normal cement generally produces 89-90 cal/g in 7 days and 90 to 100 cal/g in 28 days'

Calcium Silicate Hydrates

During the course of reaction of C_3S and C_2S with water, calcium Silicate hydrate, abbreviated C-S-H and calcium hydroxide, $Ca(OH)_2$ are formed. Calcium silicate hydrates are the most important products. It is the essence that determines the good properties of concreteit makes up 50-60 per cent of the volume of solids in a completely hydrated cement paste.

It was considered doubtful that the product of hydration of both C_3S and C_2S results in the formation of the same hydrated compound. But later on it was seen that ultimately the hydrates of C_3S and C_2S will tum out to be the same. The following are the approximate equations showing the reactions of C_3S and C_2S With water.

$$2\,(3\,CaO.SiO_2) + 6H_2O \rightarrow 3\,CaO.2\,SiO_2.\,3H_2O + 3Ca(OH)_2$$

or it can be written as $2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$

The corresponding weights involved are

$$100 + 24 \rightarrow 75 + 49.$$

Similarly, $2\,(2\,CaO.SiO_2) + 4\,H_2O \rightarrow 3Cao.2\,SiO_2.\,3H_2O + Ca(OH)_2$

or it can be written as

$$2\,C_2S + 4\,H \rightarrow C_3S_2H_3 + Ca\,(OH)_2$$

The corresponding weights involved are

$$100 + 21 \rightarrow 99 + 22$$

It can be seen that C_3S produces a comparatively lesser quantity of calcium siilicate hydrates and more quantity of $Ca(OH)_2$ than that formed in the hydration of C_2S. $Ca(OH)_2$ is not a desirable product in the concrete mass, it is soluble in water and gets leached out making the concrete porous particularly in hydraulic structures. Under such conditions it is useful to use cement with higher percentage of C_2S content.

C_3S readily reacts with water and produces more heat of hydration. It is responsible for early strength of concrete. A cement with more C_3S content is better for cold weather concreting. The quality and density of calcium Silicate hydrate formed out of C_3S is slightly intemr to that formed by C_2S. The early strength of concrete is due to C_3S

C_2S hydrates rather slowly. It is responsible for the later strength of concrete it produces less heat of hydration. The calcium silicate hydrate formed is rather dense and its specific surface is higher. In general, the quality of the proudct of hydration of C_2S is better than that produced in the hydration of C_3S.

Calcium Hydroxide

The other product of hydration of C_3S and C_2S is calcium hydroxide. It constitutes 20 to 25 per cent of the volume of solids in the hydrated paste The lack of durability of concrete, is on account of the presence of calcium hydroxide. The calcium hydroxide also reacts with sulphates present in soils or water to form calcium sulphate which further reacts with C_3A and cause deterioration of concrete. This is known as sulphate attack. To reduce the quantity of $Ca(OH)_2$ in concrete and to overcome its bad effects by converting it into cementitious product is an advancement in concrete technology. The use of blendingmaterials such as fly ash, silica fume and such other pozzolanic materials are the steps to overcome bad effect of $Ca(OH)_2$ in concrete

The only advantage is that $Ca(OH)_2$ being alkaline in nature maintain pH value around 13 in the concrete which resists the corrosion of reinforcements.

Calcium Aluminate Hydrates

The hydration of aluminates has been the subject of numerous investigations, but there is still some uncertainty about some of the reported products. Due to the hydration of C_3A, a calcium aluminate system CaO- Al_2O_3 - H_20 is formed. The cubic compound C_3AH_6 is probably the only stable compound formed which remains stable up to about 225°C

The reaction of pure C_3A with water is very fast and this may lead to flash set to prevent this flash set. To prevent this flash set gypsum is added at the time of grinding the cement clinker. The quantity of gypsum added has a bearing on the quantity of C_3A present.

The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates very fast it may contribute a little to the early days

Structure of Hydrated Cement

To understand the behaviour of concrete, it is necessary to acquaint ourselves with the structure of hydrated hardened cement paste. If the concrete is considered as two phase material namely the paste phase and the aggregate phase, the understanding of the paste phase becomes more important as it influences the behaviour of concrete to a much greater extent. It will be discussed later that the strength, the permeability, the durability, the drying shrinkage, the elastic properties, the creep and volume change properties of concrete is greatly influenced by the paste structure The aggregate phase though important, has lesser influence on the properties of concrete than the paste phase. Therefore, in our study to understand concrete, it is important that we have a deep understanding of the structure of the hydrated hardened cement paste at a phenomenological level

Transition Zone

Concrete is generally considered as two phase material i. e., paste phase and aggregates phase. At macro level it is seen that aggregate particles are dispersed in a matrix of cement paste. At the microscopic level, the complexities of the concrete begin to show up, particularly in the vicinity of large aggregate particles. This area can be considered as a third phase, the transition zone, which represents the interfacial region between the particles of coarse aggregate and hardened cement paste. Transition zone is generally a plane of weakness and, therefore, has far greater influence on the mechanical behaviour of concrete.

Although transition zone is composed of same bulk cement paste, the quality of paste in the transition zone is of poorer quality. Firstly due to internal bleeding, water accumulates below elongated, flaky and large pieces of aggregates. This reduces the bond between paste and aggregate to general. If we go into little greater detail, the size and concentration of crystalline compounds such as calcium hydroxide and ettringite are also larger in the transition zone. Such a situation account for the lower strength of transition zone than bulk cement paste in concrete.

Due to drying shrinkage or temperature variation, the transition zone develops microcracks even before a structure is loaded. When structure is loaded and at high stress levels these microcracks propagate and bigger cracks are formed resulting in failure of bond. Therefore, transition zone, generally the weakest link of the chain, is considered strength limiting phase in concrete. It is because of the presence of transition zone that concrete fails at considerably lower stress level than the strength of bulk paste or aggregate.

Sometimes it may be necessary for us to look into the structure of hardening concrete also. The rate and extent of hydration of cement have been investigated in the past using a variety of techniques. The techniques used to study the structure of cement paste include measurements or settling time, compressive strength, the quantity or heat or hydration evolved, the optical and electron microscope studies coupled with chemical analysis and thermal analysis of hydration products. Continuous monitoring of reactions by X ray diffractions and conductioncalorimetry has also been used for the study.

Measurements of heat evolved during the exothermic reactions also gives valuable insight into the nature of hydration reactions. Since approximately 50% of a total heat evolutionoccurs during the first 3 days of hydration, a continuous record of the rate of heat liberation during this time is extremely useful in understanding the degree of hydration and the resultant structure of the hardening cement paste.

The mechanical properties of the hardened concrete depend more on the physical structure of the products of hydration than on the chemical composition of the Cement. Mortar and concrete, shrinks and cracks, offers varying chemical resistance to different situations, creeps in different magnitude, and in short, exhibits complex behaviour under different conditions. Eventhough it is difficult to explain the behaviour of concrete fully and exactly, it is possible to explain the behaviour of concrete on better understanding of the structure of the hardened cement paste. Just as it is necessary for doctors to understand in great detail the anatomy of the human body to be able to diagnose disease and treat the patient with medicine or surgery, it is necessary for concrete technologists to fully understand the structure of hardened cement paste in great detail to be able to appreciate and rectify the ills and defects of the concrete.

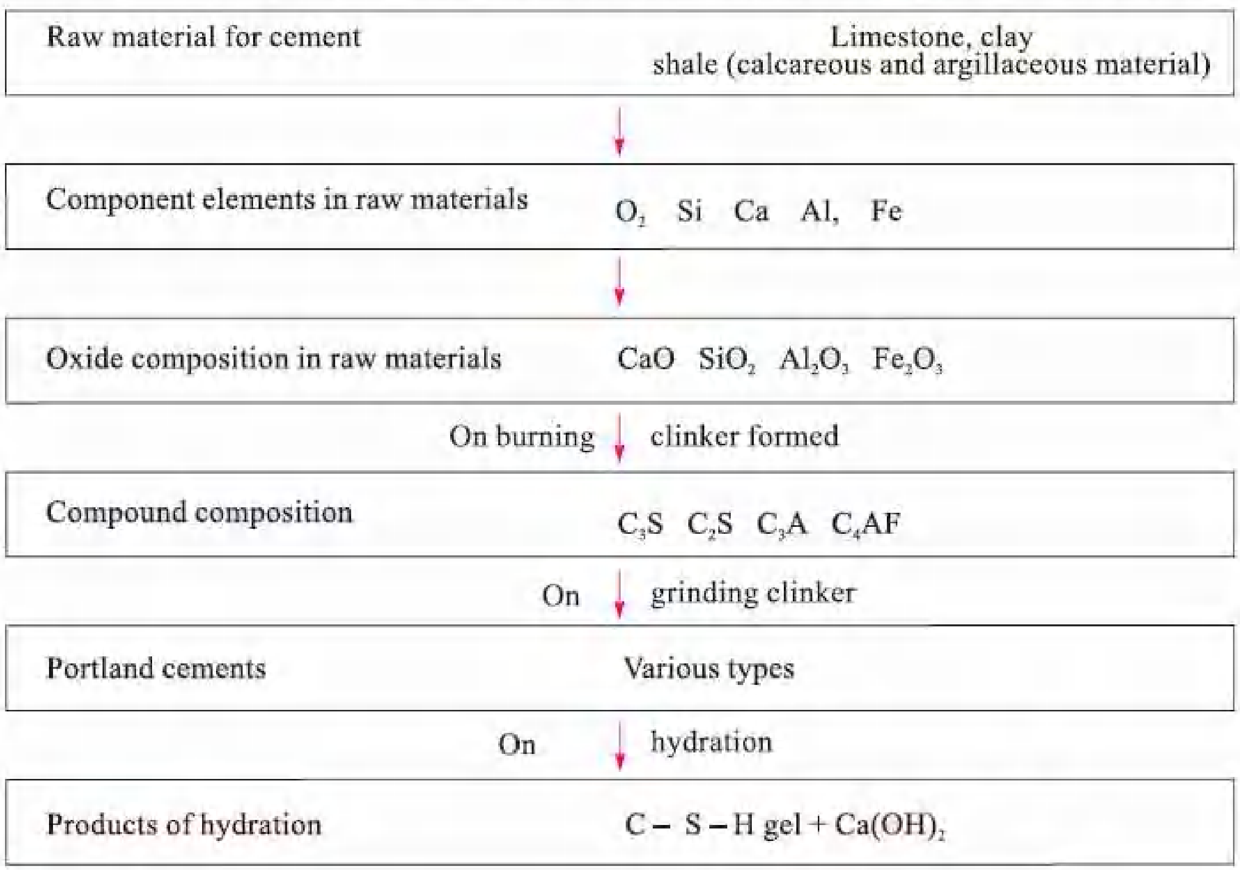
For simplicity sake we will consider only the structure of the paste phase. Fresh cement paste is a plastic mass consisting of water and cement. With the lapse of time, say one hour, the hardening paste consists of hydrates of various compounds, unhydrated cement particles and water. With further lapse of time the quantity of unhydrated cement left in the paste decreases and the hydrates of the various compounds increase. Some of the mixing water is used up for chemical reaction and some water occupies the gel pores and the remaining water remains in the paste. After a sufficiently long time (say a month) the hydrated paste can be considered to be consisting of about 85 to 90% of hydrates of the various compounds and 10 to 15 per cent of unhydrated cement. The mixing water is partly used up in the chemical reactions. Part of it occupies the gel pores and the remaining water unwanted for hydration or for filling in the gel pores causes capillary cavities. These capillary cavities may have been fully mled with water or partly with water or may be fully empty dependtng upon the age and the ambient temperature and humidity conditions.

Water Requirements for Hydration

It has been brought out earlier that C_3S requires 24% of water by weight of cement and C_3S requires 21%. It has also been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. This 23% of water chemically combines with cement and, therefore, it is called bound water. A certain quantity of water is imbibed within the gel-pores. This water is known as gel-water. It can be said that bound water and gel-water are complimentary to each other. If the quantity of water is inadequate to fill up the gel-pores, the formations of gel itself will stop and if the formation of gel stops there is no question of gel-pores being present. it has been further estimated that about 15 per cent by weight of cement is required to fill up the gel-pores. Therefore, a total 38 per cent of water by weight of cement is required for the complete chemical reactions and to occupy the space within gel-pores. if water equal to 38 per cent by weight of cement is only used it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities. On the other hand, if more than 38 per cent of water is used, then the excess water will cause undesirable capillary cavities. Therefore greater the water above the minimum required is used (38 per cent), the more will be the undesirable capillary cavities. in all this it is assumed that hydration is taking place in a sealed container, where moisture to and from the paste does not take place.

It can be seen that the capillary cavities become larger with increased water/cement ratio. With lower w/c ratio the cement particles are closer together. With the progress of hydration, when the volume of anhydrous cement increases, the product of hydration also increases. The increase in the volume of gel due to complete hydration could fill up the space earlier occupied by water upto a w/c ratio of 0.6 or so. If the w/c ratio is more than 0.7, the increase in volume of the hydrated product would never be sufficient to till up the voids created by water. Such concrete would ever remain as porous mass. This is to say that gel occupies more and more space, that once occupied by mixing water. it has been estimated that the volume of gel Would be about twice the volume of unhydrated cement**.**

Cement and hydration of Portland cement can be schematically represented as below:



GRADES OF ORDINARY PORTLAND CEMENT

Portland cement is classified into various grades according to its compressive strength. Compressive strength of the cement is obtained by testing a cube of cement mortar cube of l: 3 ratios with face area $50cm^2$ after 28 days of casting.

33 grade cement

When the 28 day compressive strength of cement is more than 33 N/mm^2, then this belongs to 33 grade. This grade conformed to I.S. 269:1989 specifications.

43 grade cement

When the 28'day compressive strength of the cement is more than 43 N/mm^2, then it is called 43 grade cement. This grade conformed to I.S. 8112:1989 specifications.

53 grade cement

When the 28 day compressive strength of the cement is more than 53 N/mm^2, then this belongs to 53 grade cement which is used for superior quality works. This grade is conformed to I.S 12269:1987 specifications.

PROPERTIES OF CEMENT

Physical properties

Fineness

- The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the development of strength.
- The disadvantages of fine grinding are that it is susceptible to airset and early deterioration.
- Maximum number of particles in a sample of cement should have a size less than about 100 microns.
- The smallest particle may have a size of about 1.5 microns.
- The particle size fraction below 3 microns has been found to have the predominant effect on the strength at one day
- 3-25 micron has a major influence on the 28 days strength.
- Increase in fineness of cement is also found to increase the drying shrinkage of concrete.
- In commercial cement it is suggested that there should be about 25-30 per cent of particles of less than 7 micron in size.
- **By and large an average size of the cement particles may be taken as about 10 micron.**

2) Initial setting time

- Initial setting time is regarded as the time elapsed between the moment that the water is added to the cement, to the time that the paste starts losing its plasticity.

- In actual construction dealing with cement paste, mortar or concrete certain time is required for mixing, transporting placing, compacting and finishing.
- During this time cement paste, mortar, or concrete should be in plastic condition.
- The time interval for which the cement products remain in plastic condition is known as the initial setting time.
- **Normally a minimum 30 minutes is given for mixing and handling operations.**

3) Final setting time

- The final setting time is the time elapsed between the moment the water is added to the cement and the time when the paste has completely lost its plasticity
- **This time should not be more than 10 hours which is often referred to as final setting time.**

4) Soundness

- It is very important that the cement after setting shall not undergo any appreciable change of volume.
- Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass.
- This will cause serious difficulties for the durability of structures when such cement is used.
- The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance.
- Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportion of sulphates.
- It should not me more than 10%

5) **Compressive strength**

The compressive Strength of hardened cement is the most important of all the properties. Therefore it is not surprising that the cement is always tested for its strength at the laboratory before the cement is used in important works. Strength of cement is indirectly found on cement sand mortar in specific proportions. It shall conform to IS 650-1991

Type of cement	3day compressive Day (N/mm^2)	7day compressive Day (N/mm^2)	28day compressive Day (N/mm^2)

33 grade	16	22	33
43 grade	23	33	43
53 grade	27	37	53

Chemical properties of cement

Indian standard specification for 33 grade cement, IS 269-1989, specifies the following chemical requirements:

(a)	*Ratio of percentage of lime to percentage of silica, alumina and iron oxide; known as Lime Saturation Factor, Not greater than 1.02 and not less than 0.66*	
(b)	*Ratio of percentage of alumina to that of iron oxide*	*Not less tan 0.66*
(c)	*Weight of insoluble residue*	*Not more than 4 per cent*
(d)	*Weight of magnesia*	*Not more than 6 per cent*
(e)	*Total sulphur content, calculated as sulphuric when anhydride (SO_3)*	*Not more than 2.5% C_3A is 5% or less. Not more than 3%, when C_3A is more than 5%*
(f)	*Total loss on ignition*	*Not more than 5 per cent*

TESTING OF CEMENT

Testing of cement can be brought under two categories:

(a) Field testing

(b) Laboratory testing.

Field Testing

It is sufficient to subject the cement to field tests when it is used for minor works. The following are the field tests:

(a) Open the bag and take a good look at the cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.

(b) Thrust your hand into the cement bag. it must give you a cool feeling. There should not be any lump inside.

(c) Take a pinch of cement and feel-between the fingers. it should give a smooth and not a gritty feeling.

(d) Take a handful of cement and throw it on a bucket full of water, the particles should float for some time before they sink.

(e)Take about 100 grams of cement and a small quantity of water and make a $th paste From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

Laboratory testing

(a) Fineness test

(b) Setting time test

(c)Strength test.

(d) Soundness test

(e) Heat of hydration test

Fineness Test

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the development of strength. Different cements are ground to different fineness. The disadvantages of fine grinding are that it is susceptible to airset and early deterioration. Maximum number of particles in a sample of cement should have a size less than about 100 microns. The smallest particle may have a size of about 1.5 microns. By and large an average size of the cement particles may be taken as about 10 micron. The particle size fraction below 3 microns has been found to have the predominant effect on the strength at one day while 3-25 micron has a major influence on the 28 days strength. Increase in fineness of cement is also found to increase the drying shrinkage of concrete. In commercial cement it is suggested that there should be about 25-30 per cent of particles of less than 7 micron in size.

Fineness of cement is tested in two ways :

(a) By seiving.

(b) By determination of specific surface (total surface area of all the particles in one gram of cement) by air-permeability apparatus. Expressed as cm^2/gmor m^2/kg. Generally Blaine Air permeability apparatus is used

Sieve Test

Weigh correctly 100 grams of cement and take it on a Standard IS Sieve No. 9 (90 microns). Break down the air-set lumps in the sample with fingers. Continuously Sieve the sample giving circular and vertical motion for a period of 15 minutes. Mechanical Sieving devices may also be used. Weigh the residue left on the sieve. This weight shall not exceed 10% for ordinary cement. Sieve test is rarely used

Standard Consistency Test

- For finding out initial setting time, final setting time and soundness of cement, and strength a parameter known as standard consistency has to be used.
- The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having to 10mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of the mould shown in Fig.
- The appartus is called vicatAppartus.
- This appartus is used to find out the percentage of water required to produce a cement paste of standard consistency.
- The standard consistency of the cement paste is some time called normal consistency

The following procedure is adopted to find out standard consistency.

1. Take about 500 gm of cement and prepare a paste with a weighed quantity of water (say 24 per cent by weight of cement for the first trial.
2. The paste must be prepared in a standard manner and filled into the Vicar mould within 35 minutes.
3. After completely filling the mould, shake the mould to expel air.
4. A standard plunger, 10 mm diameter, 50 mm long is attached and brought down to much the surface of the paste in the test block and qulckly released allowing it to sink into the paste by its own weight.
5. Take the reading by noting the depth of penetration of the plunger
6. Conduct a 2nd trial (say with 25 per cent of water) and find out the depth of penetration of plunger.
7. Similarly, conduct trials with higher and higher water/cement ratios till such time the plunger penetrates for a depth of 33-35 mm from the top.
8. That particular percentage of water which allows the plunger to penetrate only to a depth of 33-35 mm from the top is known as the percentage of water required to produce a cement paste of standard consistency.

- This percentage is usually denoted as 'P.

- The test is required to be conducted in a constant temperature (27° +2°C) and constant humidity (90%)

Setting Time Test

- The vicatAppartus shown in Fig. is used for setting time test also.
- The following procedure is adopted.

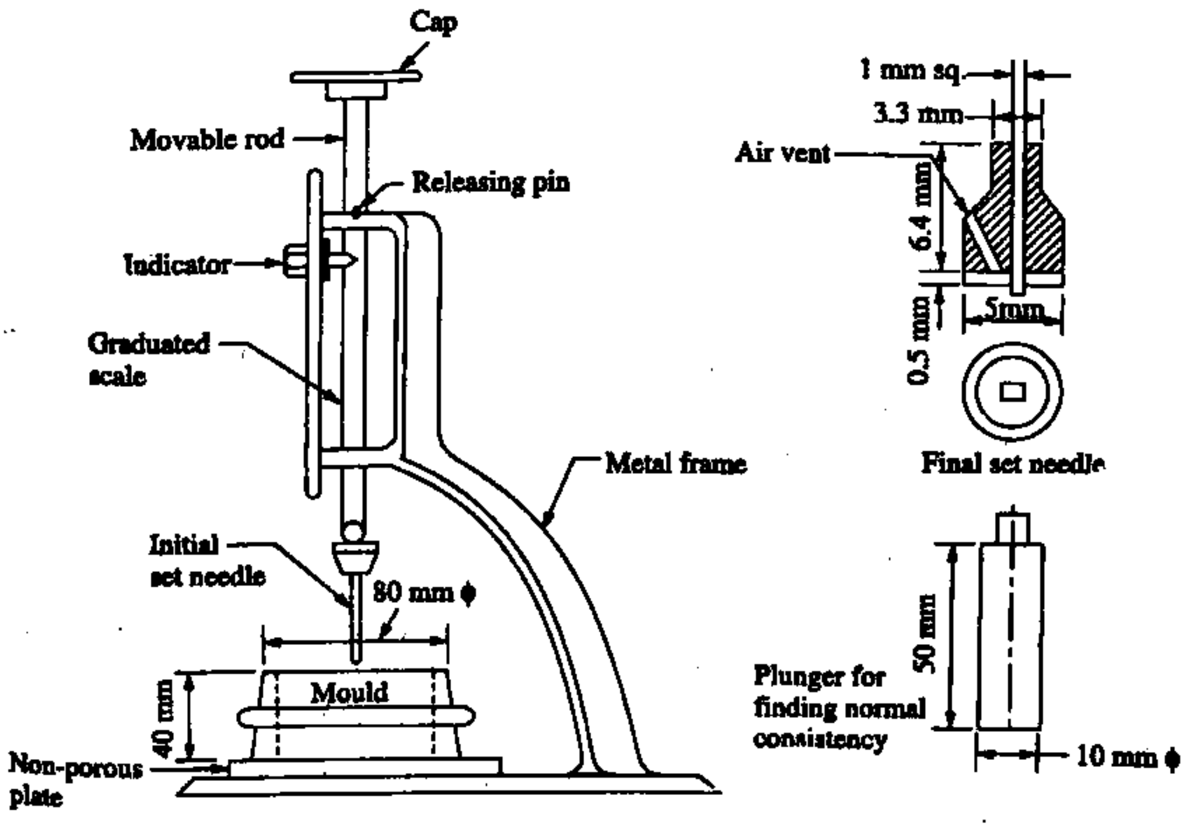
1. Take 500 gm. of cement sample and guage it with 0.85 times the water required to produce cement paste of standard consistency (0.85 P).
2. The Paste shall be guaged and filled into the Vicatmould in specified manner within 3-5 minutes
3. Start the stop watch the moment water is added to the cement.
4. The temperature of water and that of the test room, at the time of gauging shall be within 27°C+2°C.

Initial Setting Time

5. Lower the needle (C) gently and bring it in contact with the surface of the test block and quickly release.
6. Allow it to penetrate into the test the needle will completely pierce through the test block.
7. But after some time when the paste starts losing its plasticity theneedly may penetrate only to a depth of 33-35 mm from the top.
8. The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 mm from the top ls taken as initial setting time.

Final setting time

9. Replace the needle (C) of the Vicatappartus by a circular attachment (F) shown in the Fig
10. The cement shall be considered as finally set when, upon, lowering the attachment gently cover the surface of the test block the centre needle makes an impression while the circular cutting edge of the attachment fails to do so.
11. In other words the paste has attained such hardness that the centre needle does not pierce through the paste more than 0.5 mm



Vicat's apparatus.

Strength Test

Procedure

I. Take 555 gms of standard sand (Ennore sand) 185 gms of cement (i.e, ratio of cement to sand is 1:3) in a non-porous enamel tray

II. Mix them with a trowel for one minute

III. Add water of quantity P/4+ 3.0 per cent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform colour. The time of mixing should not be less than 3 minutes nor more than 4 minutes.

IV. Immediately after mixing the mortar is filled into a cube mould of size 7.06 cm. The area of the face of the cube will be equal to 50 sq cm.

V. Compact the mortar either by hand compaction in a standard specified manner or on the vibrating equipment (12000 RPM) for 2 minutes.

VI. Keep the compacted cube in the mould at a temperature of 27°C $\pm$ 2°C and at least 90 per cent relative humidity for 24 hours.

VII. Where the facility of standard temperature and humidity room is not available. the cube may be kept under wet gunny bag to simulate 90 per cent relative humidity.

VIII. After 24 hours the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.

IX. Three tubes are tested for compressive strength at the periods of 3,7 and 28 days. The compressive strength shall be the average of the strengths of the three cubes for each period respectively.

X. The strength requirements for various types of cement is shown in Table

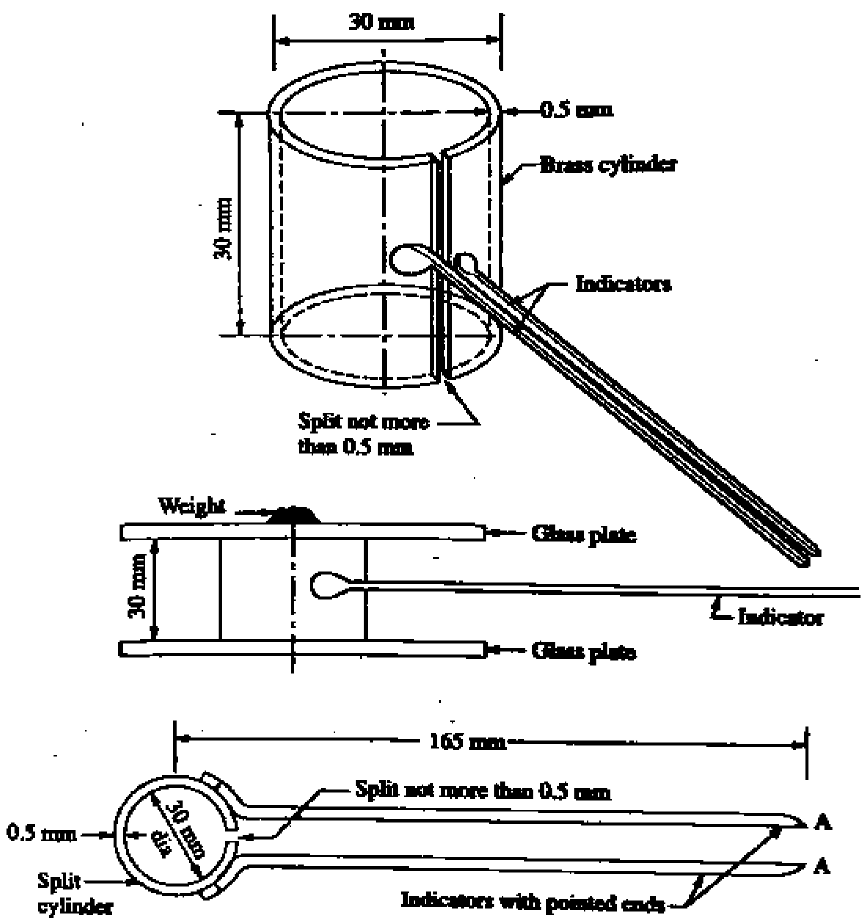
Sl. No.	Type of Cement	Compressive Strength			
		1 Day min. MPa	3 Days min. MPa	7 Days min. MPa	28 Days min. MPa
1.	33 Grade OPC (IS 269-1989)	N S	16	22	33
2.	43 Grade OPC (IS 8112-1989)	N S	23	33	43
3.	53 Grade OPC (IS 12269-1987)	N S	27	37	53

Soundness Test

It is very important that the cement after setting shall not undergo any appreciable change of volume. Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This will cause serious difficulties for the durability of structures when such cement is used. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance.

Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportion of sulphates. Unsoundness in cement does not come to surface for a considerable period of time. Therefore, accelerated tests are required to detect it. There are number of such tests in common use. The apparatus is shown in Fig. It consists of a small split cylinder of spring brass or other suitable metal. It is 30 mm in diameter and 30 mm high. On either side of the split are attached two indicator arms 165 mm long with pointed ends. Cement is gauged with 0.78 times the water required for standard consistency (0.78 P), in a standard manner and filled into the mould kept on a glass plate. The mould is covered on the top with another glass plate. The whole assembly is immersed in water at a temperature of 27°C-32°C and kept there for 24 hours.

Measure the distance between the indicator points. Submerge the mould again in water. Heat the water and bring to boiling point in about 25-30 minutes and keep it boiling for 3 hours. Remove the mould from the water, allow it to cool and measure the distance between the indicator points. The difference between these two measurements represents the Heat of Hydration expansion of cement. This must not exceed l0 mm for ordinary, rapid hardening and low heat Portland cements. if in case the expansion is more than 10 mm as tested above, the cement is said to be unsound.



Le Chatelier apparatus.

The Le Chatelier test detects unsoundness due to free lime only. This method of testing does not indicate the presence and after effect of the excess of magnesia. Indian Standard Specification stipulates that a cement having a magnesia content of more than 3 per cent shall be tested for soundness by Autoclave test which is sensitive to both free magnesia and free lime. In this test a neat cement specimen 25 x 25 mm is placed in a standard autoclave and the steam pressure inside the autoclave is raised in such a rate as to bring the gauge pressure of the steam to 21 kg/ sq cm in 1- l ¼hour from the time the heat is turned on. This pressure is maintained for 3 hours. The autoclave is cooled and the length measured again. The high steam pressure accelerates the hydration of both magnesia and lime.

No satisfactory test is available for deduction of unsoundness due to an excess of calcium sulphate. But its content can be easily determined by chemical analysis.

Types of Cement

(a) Ordinary Portland Cement

(b) Rapid Hardening Cement

(c) Extra Rapid Hardening Cement

(d) Sulphate Resisting Cement

(e) Portland Slag Cement

(f) Quick Setting Cement

(g) Super Sulphated Cement

(h) Low Heat Cement

(j) Portland Pozzolana Cement

(k) Air Entraining Cement

(l)Coloured Cement: White Cement

(m) Hydrophobic Cement

(n) Masonry Cement

(o) Expansive Cement

(p) Oil Well Cement

(q) Rediset Cement – –

(r) High Alumina Cement – IS 6452: 1989

(s) Very High Strength Cement

Rapid Hardening Cement (IS 8041–1990)

This cement is similar to ordinary Portland cement. As the name indicates it develops strength rapidly. Rapid hardening cement develops at the age of three days, the same strength as that is expected of ordinary Portland cement at seven days. The rapid rate of development of strength is attributed to the higher fineness and higher C_3S and lower C_2S content. A higher fineness of cement particles expose greater surface area for action of water and also higher proportion of C3S results in quicker hydration. Consequently, rapid hardening cement gives out much greater heat of hydration during the early period. Therefore, rapid hardening cement should not be used in mass concrete construction.

The use of rapid heading cement is recommended in the following situations:

(a) In pre-fabricated concrete construction.

(b) Where formwork is required to be removed early for re-use elsewhere,

(c) Road repair works,

(d) In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage

Extra Rapid Hardening Cement

Extra rapid hardening cement is obtained by intergrinding calcium chloride with rapid hardening Portland cement. The normal addition of calcium chloride should not exceed 2 per cent by weight of the rapid hardening cement. It is necessary that the concrete made by using extra rapid hardening cement should be transported, placed and compacted and finished within about 20 minutes. It is also necessary that this cement should not be stored for more than a month.

Sulphate Resisting Cement (IS 12330–1988)

Ordinary Portland cement is susceptible to the attack of sulphates, in particular to the action of magnesium sulphate. Sulphates react both with the free calcium hydroxide in set-cement to form calcium sulphate and with hydrate of calcium aluminate to form calcium sulphoaluminate, the volume of which is approximately 227% of the volume of the original aluminates. Their expansion within the frame work of hadened cement paste results in cracks and subsequent disruption. Solid sulphate do not attack the cement compound. Sulphates in solution permeate into hardened concrete and attack calcium hydroxide, hydrated calcium aluminate and even hydrated silicates.

The above is known as sulphate attack. Sulphate attack is greatly accelerated ifaccompanied by alternate wetting and drying which normally takes place in marine structures in the zone of tidal variations.

To remedy the sulphate attack, the use of cement with low C_3A content is found to be effective. Such cement with low C_3A and comparatively low C_4AF content is known as Sulphate Resisting Cement. In other words, this cement has a high silicate content. The specification generally limits the C3A content to 5 per cent.

The use of sulphate resisting cement is recommended under the following conditions:

(a) Concrete to be used in marine condition;

(b) Concrete to be used in foundation and basement, where soil is infested with sulphates;

(c) Concrete used for fabrication of pipes which are likely to be buried in marshy region or sulphate bearing soils;

(d) Concrete to be used in the construction of sewage treatment works

Portland Pozzolana Cement (IS 1489–1991).

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcinedclay or fly ash. Fly ash is a waste material, generated in the thermal power station, when powdered coal is used as a fuel.

It may be recalled that calcium silicates produce considerable quantities of calcium hydroxide, which is by and large a useless material from the point of view of strength or durability. If such useless mass could be converted into a useful cementitious product, it considerably improves quality of concrete. The use of fly ash performs such a role. The pozzolanic action is shown below:

Calcium hydroxide + Pozzolana + water → C – S – H (gel)

Portland pozzolana cement produces less heat of hydration and offers greater resistanceto the attack of aggressive waters than ordinary Portland cement. Moreover, it reduces the leaching of calcium hydroxide when used in hydraulic structures. However, it is important to appreciate that the addition of pozzolana does not contribute to the strength at early ages. Strengths similar to those of ordinary Portland cement can be expected in general only at later ages provided the concrete is cured under moist conditions for a sufficient period. If the Portland pozzolana cement is manufactured by using the right type of reactive pozzolanic material, the Portland pozzolanic cement will not be in any way inferior to ordinary Portland cement except for the rate of development of strength upto 7 days

It is particularly useful in marine and hydraulic construction and other mass concrete constructions. Portland pozzolanacement can generally be used where ordinary Portland cement is usable.

Advantages of PPC

(a) In PPC, costly clinker is replaced by cheaper pozzolanic material - Hence economical.

(b) Soluble calcium hydroxide is converted into insoluble cementitious products resulting in improvement of permeability. Hence it offers, alround durability characteristics, particularly in hydraulic structures and marine construction.

(c) PPC consumes calcium hydroxide and does not produce calcium hydroxide as much as that of OPC.

(d) It generates reduced heat of hydration and that too at a low rate.

(e) PPC being finer than OPC and also due to pozzolanic action, it improves the pore size distribution and also reduces the microcracks at the transition zone.

(f) Reduction in permeability of PPC offers many other alround advantages.

(g) As the fly ash is finer and of lower density, the bulk volume of 50 kg bag is slightly more than OPC. Therefore, PPC gives more volume of mortar than OPC.

(h) The long term strength of PPC beyond a couple of months is higher than OPC if enough moisture is available for continued pozzolanic action.

Portland Slag Cement (PSC) (IS 455–1989)

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and granulated blast furnace slag in suitable proportions and grinding the mixture to get a thorough and intimate mixture between the constituents. It may also be manufactured by separately grinding Portland cement clinker, gypsum and ground granulated blast furnace slag and later mixing them intimately. The quantity of granulated slag mixed with portland clinker will range from 25-65 percent. Early strength is mainly due to the cement clinker fraction and later strength is that due to the slag fraction.The resultant product is a cement which has physical properties similar to those of ordinary Portland cement.

Portland blast furnace cement is similar to ordinary Portland cement with respect tofineness, setting time, soundness and strength. It is generally recognised that the rate of hardening of Portland blast furnace slag cement in mortar or concrete is somewhat slower than that of ordinary Portland cement during the first 28 days, but thereafter increases, so that at 12 months the strength becomes close to or even exceeds those of Portland cement.

Theheat of hydration of Portland blast furnace cement is lower than that of ordinary Portland cement. So this cement can be used in mass concrete structures with advantage. In addition, it has relatively better resistant to chlorides, soils and water containing excessive amount of sulphates or alkali metals, alumina and iron, as well as, to acidic waters, and therefore, this can be used for marine works with advantage.

The major advantages are:

(a) Reduced heat of hydration;

(b) Refinement of pore structure;

(c) Reduced permeability;

(d) Increased resistance to chemical attack.

Quick Setting Cement

This cement as the name indicates sets very early. The early setting property is brought out by reducing the gypsum content at the time of clinker grinding. This cement is required to be mixed, placed and compacted very early. It is used mostly in under water construction where pumping is involved. Use of quick setting cement in such conditions reduces the pumping time and makes it economical. Quick setting cement may also find its use in some typical grouting operations.

Low Heat Cement (IS 12600-1989)

It is well known that hydration of cement is an exothermic action which produces large quantity of heat during hydration. Formation of cracks in large body of concrete due to heat of hydration has focussed the attention of the concrete technologists to produce a kind of cement which produces less heat or the same amount of heat, at a low rate during the hydration process. Cement having this property was developed in U.S.A. during 1930 for use in mass concrete construction, such as dams, where temperature rise by the heat of hydration can become excessively large. A low-heat evolution is achieved by reducing the contents of C3S and C3A which are the compounds evolving the maximum heat of hydration and increasing C2S. A reduction of temperature will retard the chemical action of hardening and so further restrict the rate of evolution of heat. The rate of evolution of heat will, therefore, be less and evolution of heat will extend over a longer period. Therefore, the feature of low-heat cement is a slow rate of gain of strength. But the ultimate strength of low-heat cement is the same as that of ordinary Portland cement.

As per the Indian Standard Specification the heat of hydration of low-heat Portland cement shall be as follows:

7 days - not more than 65 calories per gm

28 days - not more than 75 calories per gm

The specific surface of low heat cement as found out by air-permeability method is not less than 3200 sq. cm/gm. The 7 days strength of low heat cement is not less than 16 MPa in contrast to 22 MPa in the case of ordinary Portland cement. Other properties, such as setting time and soundness are same as that of ordinary Portland cement.

Portland Pozzolana Cement (IS 1489–1991)

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcined clay or fly ash.

Hydrophobic cement (IS 8043-1991)

Hydrophobic cement is obtained by grinding ordinary Portland cement clinker with waterrepellant film-forming substance such as oleic acid, and stearic acid. The water-repellant filmformed around each grain of cement, reduces the rate of deterioration of the cement duringlong storage, transport, or under unfavourable conditions. The film is broken out when thecement and aggregate are mixed together at the mixer exposing the cement particles fornormal hydration. The film forming water-repellant material will entrain certain amount of airin the body of the concrete which incidentally will improve the workability of concrete.

Air-Entraining Cement

Air-entraining cement is not covered by Indian Standard so far. This cement is made by mixing a small amount of an air-entraining agent with ordinary Portland cement clinker at the time of grinding. The following types of air-entraining agents could be used:

(a) Alkali salts of wood resins.

(b) Synthetic detergents of the alkyl-aryl sulphonate type.

(c) Calcium lignosulphate derived from the sulphite process in paper making.

(d) Calcium salts of glues and other proteins obtained in the treatment of animal hides

These agents in powder, or in liquid forms are added to the extent of 0.025–0.1 per cent by weight of cement clinker.

There are other additives including animal and vegetable fats, oil and their acids could be used. Wetting agents, aluminium powder, hydrogen peroxide could also be used.

Air-entraining cement will produce at the time of mixing, tough, tiny, discrete non-coalesceing air bubbles in the body of the concrete which will modify the properties of plastic concrete with respect to workability, segregation and bleeding. It will modify the properties of hardened concrete with respect to its resistance to frost action

Expansive Cement

Concrete made with ordinary Portland cement shrinks while setting due to loss of free water. Concrete also shrinks continuously for long time. This is known as drying shrinkage. There has been a search for such type of cement which will not shrink while hardening and thereafter. This type of cement which suffers no overall change in volume on drying is known as expansive cement. Cement of this type has been developed by using an expanding agent and a stabilizer very carefully. Generally, about 8-20 parts of the sulphoaluminate clinker are mixed with 100 parts of the Portland cement and 15 parts of the stabilizer. Since expansion takes place only so long as concrete is moist, curing must be carefully controlled. The use of expanding cement requires skill and experience.

Oil-Well Cement (IS 8229-1986)

Oil-wells are drilled through stratified sedimentary rocks through a great depth in search of oil. It is likely that if oil is struck, oil or gas may escape through the space between the steel casing and rock formation. Cement slurry is used to seal off the annular space between steel casing and rock strata and also to seal off any other fissures or cavities in the sedimentary rock layer. The cement slurry has to be pumped into position, at considerable depth where the prevailing temperature may be upto 175°C. The pressure required may go upto 1300 kg/cm^2. The slurry should remain sufficiently mobile to be able to flow under these conditions for periodsupto several hours and then hardened fairly rapidly. It may also have to resist corrosive conditions from sulphur gases or waters containing dissolved salts. The type of cement suitable for the above conditions is known as Oil-well cement. The desired properties of Oil-well cement can be obtained in two ways: by adjusting the compound composition of cement or by adding retarders to ordinary Portland cement.

Hydrophobic cement (IS 8043-1991)

Hydrophobic cement is obtained by grinding ordinary Portland cement clinker with waterrepellant film-forming substance such as oleic acid, and stearic acid. The water-repellant filmformed around each grain of cement, reduces the rate of deterioration of the cement duringlong storage, transport, or under unfavourable conditions. The film is broken out when thecement and aggregate are mixed together at the mixer exposing the cement particles fornormal hydration. The film forming water-repellant material will entrain certain amount of airin the body of the concrete which incidentally will improve the workability of concrete.

Blended Cement

Blended cement is obtained by mixing OPC with mineral admixtures or additives like fly ash, slag or silica fumes. Blended cements are now being considered superior as compared to conventional OPC category of cements.

Presently in India about 30% of the total production is blended cement. This figure is likely to increase sharply with the increase in awareness of use of blended cement. In UK & USA, the usage of blended cement is nearly 90% of the total production. Durability problem can be effectively tackled by reducing the permeability of the concrete using blended cement.

Advantages of Blended Cement

The advantages of using blended cement can be broadly be divided in two categories i.e.

1. Technical advantages and
2. Environmental advantages

1. Technical Advantages

- It reduces water demand and therefore water-cement ratio can be reduced.
- It improves workability for the same water content.

- The blended cements are finer as compared to OPC, therefore the permeability of concrete is less. This results into improved durability.

2. Environmental Advantages

- **Energy saving**: Blended cements are obtained by adding mineral admixtures with OPC. The energy, which would have otherwise been utilized for production of OPC, is thus saved. This saving is to the tune of 0.8 to 1.2 MWH/ton of cement.
- **Conservation of natural resources**: The used mineral admixtures are the waste products of thermal and steel plants. By using these products, we are conserving the precious minerals like lime stone, clay and silica etc.
- **Pollution control**: By reducing the production of cement, pollution is also controlled as cement is an energy intensive product. It has been estimated that 7% of total pollution is only due to cement production which can proportionately be reduced if more blended cement is used.

Note: Presently in India about 30% of the total production is blended cement. This figure is likely to increase sharply with the increase in awareness of use of blended cement. In UK & USA, the usage of blended cement is nearly 90% of the total production. Durability problem can be effectively tackled by reducing the permeability of the concrete using blended cement.

CLASSIFICATION OF AGGREGATES

Classification based on origin

Based on origin the aggregates can be classified as natural aggregates and artificial aggregates.

a) Natural aggregates

Natural aggregates are originated from natural rock masses. It is obtained in the form of sand, gravel, crushed rock, pit sand etc.

b) Artificial aggregates

Artificial aggregates are manufactured from raw materials. The commonly available artificial aggregates are expanded clay, shale, slate, broken brick bat, blast furnace stag etc.

Classification based on size

Based on origin the aggregates can be classified as Fine aggregates and Coarse aggregates.

a) Fine aggregates

The aggregates, which are passing through, the IS: 4 .75 mm sieve are called fine aggregates.

b) Coarse aggregates

The aggregates, which are passing through, the IS: 4 .75 mm sieve are called coarse aggregates.

Classification based onshape

Based on the shape of the aggregate, it can be classified as rounded, irregular, flaky, angular, elongated etc.

a) Rounded aggregates

These aggregates are with rounded shape due to the action of water attrition. The aggregate collected from river or seashore belongs to this category.

b) Irregular or partially rounded aggregate

This aggregate is naturally irregular or partly shaped by attrition and have rounded edges. Pit sand, gravel etc., belong to this class.

c) Angular aggregates

They possess sharp edges and rough surfaces. All types of crushed rock fall under this category.

d) Flaky aggregates

The aggregates with less thickness compares to width and length. The concrete made with this aggregate is of poor quality.

e) Elongated aggregate

When the length of aggregate is considerably greater than the other two dimensions, it is called elongated. The concrete produced by using this aggregate is of poor quality and is less

Based on unit weight

Based on unit weight of the aggregate, it can be light weight, Normal weight and Heavy weight

a) Light weight aggregates

Unit weight - 12kN/m^3 or 1200kg/m^3

b) Normal weight aggregates

Unit weight - 15kN/m^3 or 1500kg/m^3

c) Heavy weight aggregates

Unit weight - 20kN/m^3 or 2000kg/m^3

Based on source

According to the natural sources from where aggregate is obtained it is classified as i) Pit sand ii) River sand iii) Sea sand (iv) Manufactured sand

i) Pit sand

It is collected by digging pits in the ground at a depth of 1.5m to 2m. Pit sand consists of sharp granular grains which are free from salts. It is suitable for making mortar.

ii) River sand

This sand is obtained from banks or beds of rivers. It consists of fine, rounded grains. Colour of river sand is almost white. It is widely used for all purposes.

iii) Sea sand

This sand is obtained from sea shores. It consists of fine rounded grains. The sea sand is not generally used for engineering purposes as it contains salts.

(iv) Manufactured Sand

As the availability of natural sand is getting depleted concrete industry will have to go formanufactured sand prepared from rocks of good quality. They are angular in shape compared to thesmooth natural sand. Manufactured sand is crushed. Then it is sieved through sieves of different sizes and artificially mixed to suit the required gradation. The main advantages of M Sand are

(i) It is free from impurities like organic matters, dust, chemicals etc. as wet sieving is done during its manufacture.
(ii) It is economical as it can also be prepared from the byproduct of crusher units

Sampling-

The method of sampling shall be in accordance with IS: 2430-1969. The amount of material required for each test shall be as specified in the relevant method of test given in IS: 2386 (Part I)-1963 to IS: 2386 (Part VIII)1963.

TESTING OF AGGREGATES

Tests for Grading of aggregates

- To ascertain the grading of aggregates sieve analysis is conducted separately for coarse and fine aggregates.
- The sieves used for coarse aggregates have openings of 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm.
- A set of sieves with Openings 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm are used for fine aggregates.
- Minimum weight of sample to be used for sieving different sizes of aggregates are shown in table below

Minimum weight of sample for Sieve Analysis (IS: 2386 (Part I) – 1963)

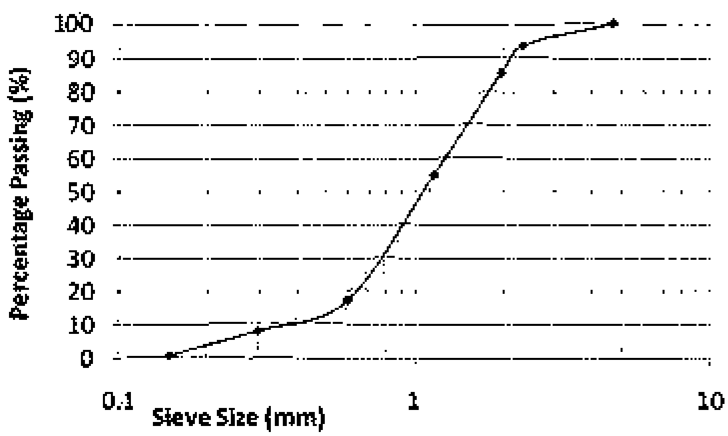
Maximum size present in substantial proportions	*Minimum weight of sample to be taken for sieving*
mm	kg
63	50
50	35
40 or 31.5	15
25	5
20 or 16	2
12.5	1
10	0.5
6.3	0.2
4.75	0.2
2.36	0.1

- Sieves are mounted one over the other in order of Size, with larger sieve on the top.
- Grading pattern of a sample of C .A or FA is assessed by sieving a sample successively through all the Sieves mounted one over the other in order of Size, with larger sieve on the top.
- Sieving can be done either manually or mechanically
- In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve.
- Operation should be continued till such time that almost no particle is passing through.
- Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than hand sieving.
- Find the weight of sample retained in each sieves

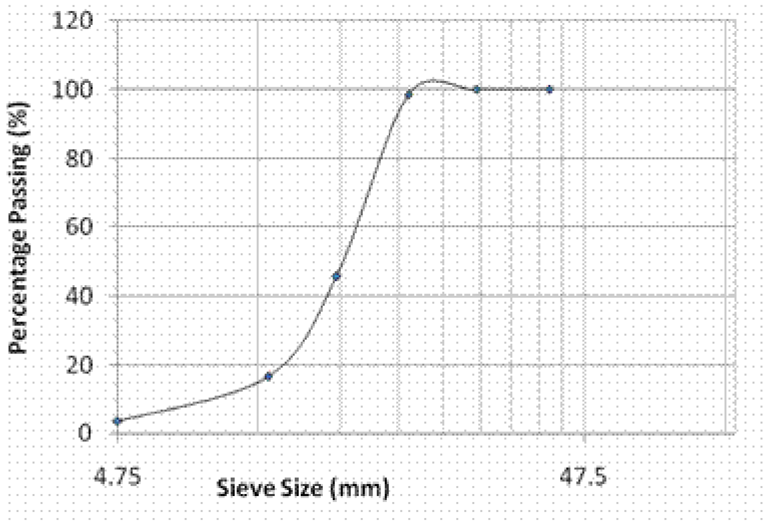
- Values are tabulated as shown

Designation Of sieve	Sieve Opening	Weight retained	% of Weight retained	Cumulative % of Weight retained	% finer

- The results of a sieve analysis can be grasped much more easily if represented graphically and for this reason, grading curves are extensively used.
- In the grading graph commonly used, the ordinate represents percentage finer and the abscissa shows the sieve opening plotted to logarithmic scale.
- By using such a graph (partials size distribution curve) it is possible to see at a glance whether the grading of a given sample conforms to that specified , or is too coarse or too fine or deficient in a particular size;



Particle size Distribution Curve for Sand



Particle size Distribution Curve for Crushed Stone

As per IS 2386 (Part VII) fine aggregate can be graded in to the zone depending upon percentage of fines retained on each size.

Fine aggregate

IS Sieve Designation	Percentage Passing			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
600 micron	15 – 34	35 – 59	60 – 79	80 – 100
300 micron	5 – 20	8 – 30	12 – 40	15 – 50
150 micron	0 – 10	0 – 10	0 – 10	0 – 15

Coarse aggregate

I.S. Sieve Designation	%age passing for graded aggregate of nominal size			
	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	-	-	-
63 mm	-	-	-	-
40 mm	95 to 100	100	-	-
20 mm	30 to 70	95 to 100	100	100
16 mm	-	-	90 to 100	-
12.5 mm	-	-	-	90 to 100
10 mm	10 to 35	25 to 55	30 to 70	40 to 85
4.75 mm	0 to 5	0 to 10	0 to 10	0 to 10
2.36 mm	-	-	-	-

- A term known as "Fineness Modulus" (FM) is being used.
- F.M is a ready index of coarseness or fineness of the material.
- Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the Standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100
- Many a time, fine aggregates are designated as coarse sand, medium sand and fine sand

The following limits may be taken as guidance:

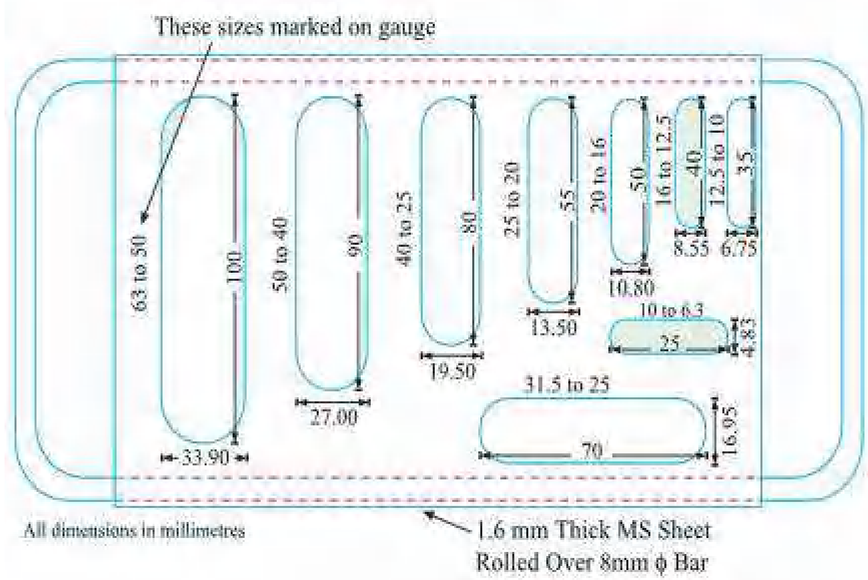
Fine sand	:	Fineness Modulus	:	2.2 - 2.6
Medium sand	:	F.M.	:	2.6 - 2.9
Coarse sand	.	F.M.	:	2.9 - 3.2

A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Test for Determination of Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm

This test is conducted by using a metal thickness gauge, of the description shown in Fig.



Procedure

(i) A sufficient quantity of aggregate is taken such that a minimum number of 200 pieces of any fraction can be tested.

(ii) Each fraction is gauged in turn for thickness on the metal gauge.

(iii) The total amount passing in the guage is weighed to an accuracy of 0.1 per cent of the weight of the samples taken.

(iv) The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.

Table shows the standard dimensions of thickness and length gauges

Dimensions of Thickness and Length Gauges
(IS: 2386 (Part I) – 1963)

Size of Aggregate Thickness		Length of Gauge* mm	Gauge† mm
Passing through IS Sieve	Retained on IS Sieve		
63 mm	50 mm	33.90	–
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	–
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10.0 mm	6.75	20.2
10.0 mm	6.3 mm	4.89	14.7

* This dimension is equal to 0.6 times the mean Sieve size.
† This dimension is equal to 1.8 times the mean Sieve size.

Test tor Determination of Elongation Index

The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using metal length guage of the description shown in Fig. 3.

Procedure

(i) A sufficient quantity of aggregate is taken to provide a minimum number of 200 pieces of any fraction to be tested.

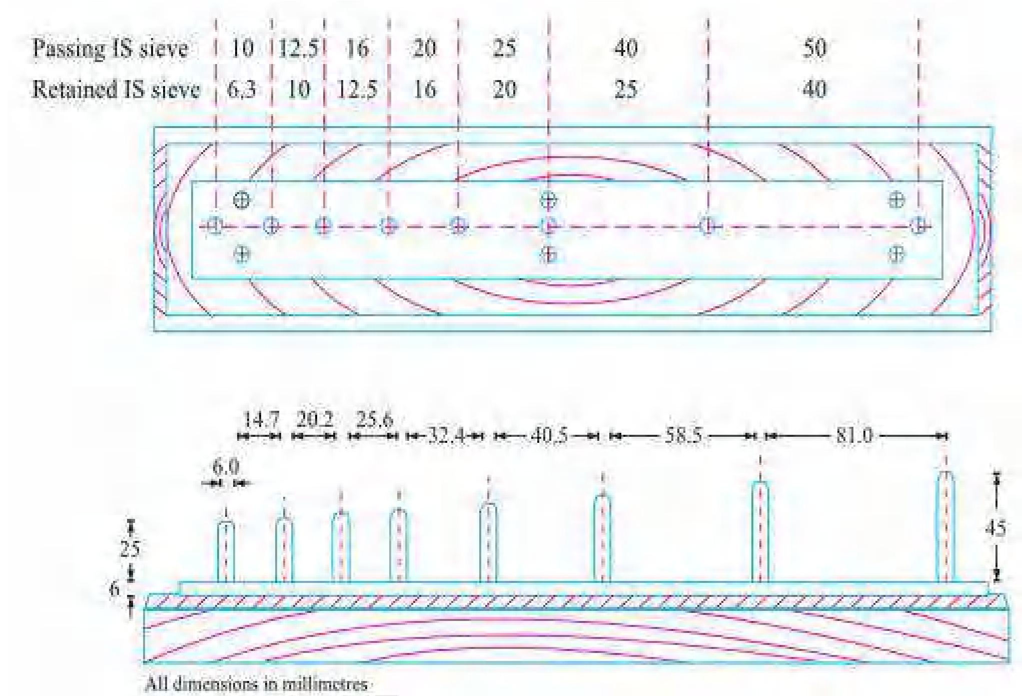
(ii) Each fraction shall be gauged individually for length on the metal guage.

(iii)The guage length used shall be that specified in column of 4 of above Table for the appropriate size of material.

(iv)The total amount retained by the guage length shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test samples taken.

(v) The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged.

The presence of elongated particles in excess of 10 to 15 per cent is general considered undesirable but laid no recognized limits are laid down



Test for Determination of Specific Gravity of coarse aggregate

Indian Standard Specification lS : 2386 (Part Ill) of I963 gives various procedures to find out the specific gravity of different sizes of aggregates

The following procedure is applicable to aggregate size larger than 10 mm.

(i) A sample of aggregate not less than 2 kg is taken it is thoroughly washed to remove the finer particles and dust adhering to the aggregate

(ii) It is then placed in a Wire basket and immersed in distilled water at a temperature between 22° to 32°C

(iii) Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per sec. During the operation, care is taken that the basket and aggregate remain completely immersed in water.

(iv) They are kept in water for a period of 24 + 1/2 hours afterwards.

(v) The basket and aggregate are then jolted and weighed (weight A_1) in water at a temperature 22° to 32° C.

(vi) The basket and the aggregate are then removed from water and allowed to drain for a few minutes

(vii) Then the aggregate is taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth

(viii) The aggregate is transferred to the second dry cloth and further dried.

(ix) The empty basket is again immersed in water jolted 25 times and weighed in water (weight A_2)

(x) The aggregate is exposed to atmosphere away from direct sunlight for not less than l0 minutes until it appears completely surface dry

(xi) Then the aggregate is weighed in air (weight B).

(xii) Then the aggregate is kept in the oven at a temperature of 100 to l 10°C and maintained at this temperature for 24 $\pm$ l/2 hours.

(xiii) It is then cooled in the airtight container, and weighed (weightC)

$$\text{Apparent Sp. Gravity} = \frac{C}{C-A}$$

$$\text{Specific Gravity} = \frac{C}{B-A}$$

$$\text{Water absorption} = \frac{100\,(B-C)}{C}$$

(i) Where

A=the weight in gm of the saturated aggregate in water (A-A2),

B=the weight in gm of the saturated surface-dry aggregate In air, and

C=the weight in gm of oven dried aggregate in air.

Specific gravity of fine aggregate

(I) Take about 500g of sample and place it in the pycnometer.

(II) Pour distilled water into it until it is full.

(III) Eliminate the entrapped air by rotating the pycnometer on its side ,the hole in the apex of the cone being covered with a finger.

(IV) Wipe out the outer surface of pycnometer and weigh it (W)

(V) Transfer the contents of the pycnometer into a tray , care being taken to ensure that all the aggregate is transferred .

(VI) Refill the pycnometer with distilled water to the same level .

(VII) Find out the weight (W_1)

(VIII) drink water from the sample through a filter paper .

(IX) Place the sample in oven in a tray at a temperature of 100ºC to 110º C for 24±0.5 hours ,during which period ,it is stirred occasionally to facilitate drying

(X) Cool the sample and weigh it (W_2)

Apparent specific gravity = (weight of dry sample/weight of equal volume of water)

$$= W_2/(W_2 - (W - W_2))$$

Test for Determination of Bulk Density and Voids

Bulk density is the weight of material in a given volume.

It is normally expressed in kg per litre.

A cylindrical measure preferably machined to accurate internal dimensions is used for measuring bulk density.

The size of the container for measuring bulk density is shown in Table.

Size of Container for Bulk Density Test

Size of Largest Particles	*Nominal Capacity*	*Inside Diameter*	*Inside Height*	*Thickness of Metal*
	litre	*cm*	*cm*	*mm*
4.75 mm and under	*3*	*15*	*17*	*3.15*
Over 4.75 mm to 40 mm	*15*	*25*	*30*	*4.00*
Over 40 mm	*30*	*35*	*31*	*5.00*

Procedure

(i) The cylindrical measure is filled about 1/3 each time with thoroughly mixed aggregate and tamped with 25 strokes by a bullet ended tamping rod, 16 mm diameter and 60 cm long

(ii) The measure is carefully struck off level using tamping rod as a straight edge.

(iii) The net weight of the aggregate in the measure is determined and the bulk density is calculated in kg/lltre.

$$Bulk\ dinsity = \frac{\text{net weight of the aggregate in kg}}{\text{capacity of the container in litre}}$$

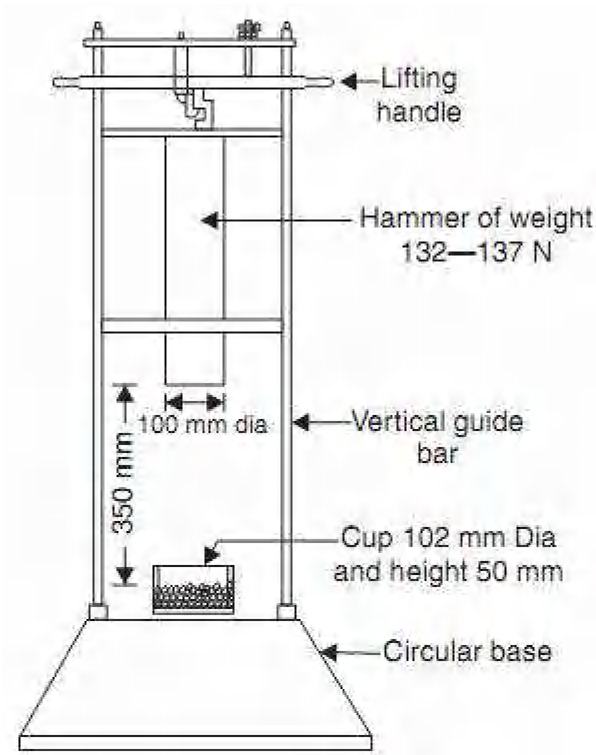
$$Percentage\ of\ voids = \frac{G_s - \gamma}{G_s} \times 100$$

G_s = specific gravity of aggregate

γ = bulk dinsity in kg/litre.

Test tor determination of aggregate Impact value

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact.



Procedure

(i) The test sample consists of aggregate passing through 12.5 mm and retained on 10 mm I.S Sieve.

(ii) The aggregate shall be dried in an oven for a period of four hours at a temperature of 100°C to 110°C and cooled.

(iii)The aggregate is filled about one third full and tamped with 25 strokes by the tamping rod.

(iv) A further similar quantity of aggregate is added and tamped n the standard manner.

(v) The measure is filled to over-flowing and then struck off level.

(vi) The net weight of the aggregate in the measure is determined (weight A) and this weight of aggregate shall be used for the duplicate test on the same material.

(vii) The whole sample is filled into a cylindrical steel cup firmly fixed on the base of the machine.

(viii) A hammer weighing about l4 kgs is raised to a height of 380 mm above the upper surface of the aggregate in the cup and allowed to fall freely on the aggregate.

(ix) The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second.

(x) The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve.

(xi) The fraction passing the sieve is weighed to an accuracy of 0.1 gm. (weight B). The fraction retained on the sieve is also weighed (weight C).

(xii) If the total weight (B +C) is less than the initial weight A by more than one gm the result shall be discarded and a fresh test made

(xiii) Two tests are made.

(xiv) The ratio of the weight of fines formed to the total sample weight in each test is expressed as percentage.

$$\text{Aggregate Impact Value} = \frac{B}{A} \times 100$$

where,

B = weight of fraction passing 2.36 mm I.S. Sieve.

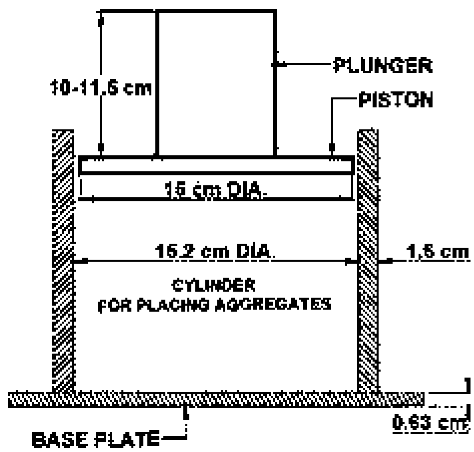
A = weight of oven-dried sample.

The aggregate impact value should not be more than 45 per cent by weight for aggregates used for concrete other than wearing surfaces and 30 per cent by weight for concrete to be used as wearing surfaces, such as runways, roads and pavements.

Test for determination of aggregate crushing value

- About 6.5 kg materials consisting of aggregates passing 12.5 mm and retained on 10 mm Sieve is taken.
- The aggregate in a surface dry condition is filled into the standard cylindrical measure in three layers approximately of equal depth.

- Each layer is tamped 25 times with the tamping rod and finally levelled off using the tamping rod as Straight edge.
- The weight of the sample contained in the cylinder measure is taken (A).
- The cylinder of the test apparatus with aggregate filled in a standard manner is put in position on the base-plate and the aggregate is carefully levelled and the Plunger inserted horizontally on this surface. The plunger should not jam in the Cylinder.
- The apparatus with the test sample and plunger in position is placed on the compression testing machine and a loaded uniformly up to a total load of 40 tons in 10 minutes time.



- The load is then released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S Sieve.
- The fraction passing the sieve is weighed (B)

The aggregate crushing value = Bx100/A

Where

B = weight of fraction passing 2.36 mm sieve,

A = weight of surface-dry sample taken in mould.

The aggregate crushing value should not be more than 45 per cent for aggregate used for concrete other than for wearing surfaces and 30 per cent for concrete used for wearing surfaces such a runways, roads and air field pavements

Test tor determination of aggregate abrasion value

Indian Standard 2386 (Part IV) of 1963 covers two methods for finding out the abrasion value of coarse aggregates: namely, by the use of Deval abrasion testing machine and by the use of Los Angeles abrasion testing machine. However, the use of Los Angeles abrasion testing machine gives a better realistic picture of the abrasion resistance of the aggregate. This method is only described herein.

The test involves taking specified quantity of standard size material along with specified number of abrasive charge in a standard cylinder and revolving if for certain specified revolutions.

Table gives the detail of abrasive charge which consists of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 to 445 gm.

Specified Abrasive Charge

Grading	*Number of spheres*	*Weight of charge (gm)*
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

The test sample consist of clean aggregate which has ben dried in an oven at 105°C to 110°C and it should conform to one of the gradings shown in Table

Gradings of Test Samples

Sieve Size		*Weight in gm. of Test Sample For Grade*						
Passing	*Retained on*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
mm	mm							
80	63	-	-	-	-	2500	-	-
63	50	-	-	-	-	2500	-	-
50	40	-	-	-	-	5000	5000	-
40	25	1250	-	-	-	-	5000	5000
25	20	1250	-	-	-	-	-	5000
20	12.5	1250	2500	-	-	-	-	-
12.5	10	1250	2500	-	-	-	-	-
10	6.3	-	-	2500	-	-	-	-
6.3	4.75	-	-	2500	-	-	-	-
4.75	2.36	-	-	-	5000	-	-	-

- Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and the machine is rotated at a speed of 20 to 33 rev/min.
- For gradings A, B, Cand D, the machine is rotated for 500 revolutions.
- For gradings E, F and G it is rotated 1000 revolutions.

- At the completion of the above number of revolution, the material is discharged from the machine and sieved on a l .7 mm IS Sieve. The material coarser than 1.7 mm IS Sieve is washed, dried in an oven at 105° to 110°C to a substantially constant weight and accurately weighed to the nearest gram.
- The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample. This value is reported as the percentage of wear.

The percentage of wear should not be more than 16 per cent for concrete aggregates.

Bulking of sand

A very simple test may be carried out to determine the percentage of bulking of sand. The procedure that is followed is as under:

(i) The sample of sand that is to be tested is taken in a container. It should be two-third filled

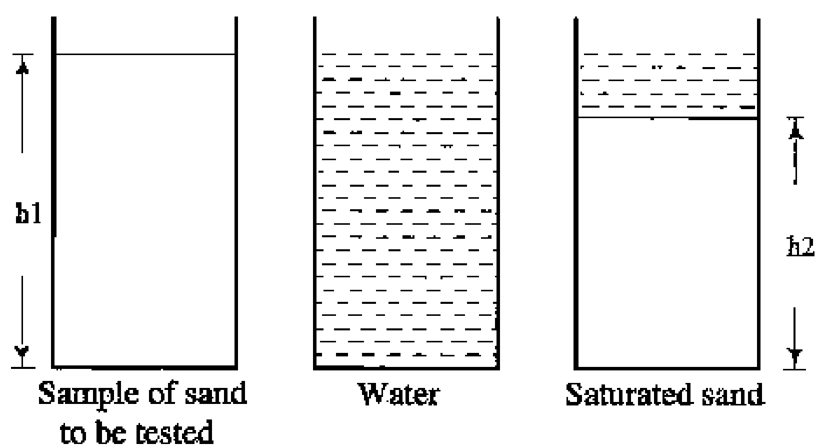
(ii) Let us assume the height measure as h_1 as in the figure.

(iii) Now, the sand is taken out of the container. During this process of taking out sand, it should be noted that there is no loss of sand.

(iv) After taking all the sand out carefully, the container is filled with water.

(iv) Now slowly the sand is dropped in the container and it is then thoroughly stirred by the means of rod.

(vi) At last again measure the height of sand. Say it is h_2



Bulking of sand is calculated as, $= (h_1-h_2)/h_2$

Test for Determination of Organic impurities

- This test is an approximate method for estimating whether organic compounds are present in the natural sand in an objectionable quantity or within the permissible limit.
- A 350 ml graduated dear glass bottle is filled no the 75 ml mark with 3 per cent solution of sodium hydroxide in water.
- The sand is added gradually until the volume measured by the sand layer is l25 ml.
- The volume is tried made up to 200 ml by adding more solution.
- The bottle is then stoppered and shaken vigorously.
- Roding also may be permitted to dislodge any organic matter adhering to the natural sand by using glass rod.
- The liquid is then allowed to stand for 24 hours.
- The colour of this liqurd after 24 hours is compared with a standard solution freshly prepared, as follows

➢ Add 2.5 ml of 2 per cent solution of tannic acid in 10 per cent alcohol, to 97.5 ml of a 3 per cent sodium hydroxide solution.

➢ Place in a 350 ml bottle, stopper, shake vigorously and allow to stand for 24 hours before comparison with the solution above

➢ Alternatively, an instrument or coloured acetate sheets for making the comparison can be obtained, but it is desirable that these should be verified on receipt by (mason with the standard solution.

ARTIFICIAL AGGREGATES

Brick Bats

Brick bats are one of the types of aggregates used in certain places where natural aggregates are not available or costly. The brick bat aggregates cannot be really brought under light-weight aggregates because the concrete made with this aggregate will not come under the category of light-weight concrete. However since the weight of such concrete will be lessthan the weight of normal concrete it is included here. Wherever brick bat aggregates are used, the aggregates are made from slightly overburnt bricks, which will be hard and absorb less water. Brick bat aggregates are also sometimes used in conjunction with high alumina cement for the manufacture of heat resistant concrete.

Cinder, Clinker and Breeze

The term clinker, breeze and cinder are used to cover the material partly fused or sintered particles arising from the combustion of coal. Cinder aggregates undergo high drying shrinkage and moisture movement. Cinder aggregates have been also used for making building blocks for partition walls, for making screeding over flat roofs and for plastering purposes.

The clinker or cinder aggregates is often unsounddue to the presence of excessiveunburnt coal particles. Sometimes unburnt particles may be present as much as 15 to 25%. This high proportion of coal expand on wetting and contract on drying which is responsible for the unsoundness of concrete made with such aggregate.

Foamed Slag

Foamed slag is one of the most important types of light-weight aggregates. It is made by rapidly quenching blast furnace slag, a by-product, produced in the manufacture of pig iron. If the cooling of the slag is done with a large excess of water, granulated slag is formed which is used in the manufacture of blast furnace slag cement. If the cooling done with a limited amount of water, in such a way as to trip steam in mass, it produces a porous, honeycombed material which resembles pumice. Sometimes, the molten slag is rapidly agitated with a limited amount of water and the steam and gas produced are made to get entrapped in the mass. Such a product is also called foamed slag or expanded slag.

Bloated Clay

When certain glass and shales are heated to the point of incipient fusion, they expand or what is termed as bloat to many times their original volume on account of the formation of gas within the mass at the fusion temperatures. The cellular structure so formed is retainedon cooling and the product is used as light-weight aggregate.

Sintered Fly Ash (Pulverised Fuel Ash)

Sintered fly ash is one of the most important types of structural light-weight aggregate used in modern times. Fly ash is finely divided residue, comprising of spherical glassy particles, resulting from the combustion of powdered coal. By heat treatment these small particles can be made to combine, thus forming porous pellets or nodules which have considerable strength.

Exfoliated Vermiculite

Raw vermiculite is a micaceous mineral. When heated withcertain percentage of water it expands by delamination in the same way as that of slate orshale. This type of expansion is known as exfoliation. Due to exfoliation, the vermiculiteexpands many times its original volume. The fully exfoliated vermiculite which may haveexpanded even as much as 30 times will have a density of only 60 to 130 kg/m^3. The concretemade with vermiculite as aggregate, therefore, will have very low density and hence very lowstrength. This concrete is used for insulating purposes. It is also used for in situ roof and floorscreeds or for the manufacture of blocks, slabs and tiles which are used for sound insulationand heat insulation. Vermiculite concrete products can be cut, sawn, nailed or screwed. This can also be used as a heat resistant material being non-inflammable. Vermiculite plaster made in conjunction with gypsum is completely incombustible in addition to possessing sound absorption quanlity and thermal insulation characteristics.

Expanded Perlite

Perlite is one of the natural volcanic glasses like pumice. This when crushed and heatedto the point of incipient fusion at a temperature of about 900 to 1100°C it expands to forma light cellular material with density of about 30 to 240 kg/m^3. This light material is crushed carefully to various sizes and used in concrete. Due to its very low density this is also used for insulation grade concrete.