

### UNIT 3 PROPERTIES OF FRESH CONCRETE

Fresh concrete - Workability - Factors affecting workability - Measurement of workability - Segregation Bleeding - Concrete manufacturing - Convention - Ready mix and Advantage of Ready mix - Finishing. Compaction Curing - Strength of concrete - Elasticity - Creep - Shrinkage - elastic behavior of concrete - Durability of concrete Factors affecting strength of concrete and Durability of concrete - Cracks in concrete - Chemical attacks-carbonation. Durability of concrete: effect of Admixtures on properties of concrete causes of concrete deterioration, alkali aggregate reaction, deterioration by chemical actions, concrete in marine environment

#### What is concrete?

Concrete is one of the most commonly used building materials. Concrete is a **composite material** made from several readily available constituents (aggregates, sand, cement, water). Concrete is a versatile material that can easily be mixed to meet a variety of special needs and formed to virtually any shape.

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material.



In order to increase the strength of concrete chemical admixtures are also added. Chemical admixtures like;

1. Super plasticizers – Salts of organic sulphonates Ligno sulphonates, Sulphonated melamine formaldehyde (SMF), Sulphonated naphthalene formaldehyde (SNF) Polycarboxylic ether (PCE)
2. Air-entraining agents - Natural wood resins , Synthetic detergents and Salts of petroleum acids) ,
3. Accelerators - Inorganic Calcium chloride, Formates, Nitrates Thiocyanates Silicates Aluminates
4. Retarders - Organic Chemicals- Carbohydrates Hydroxycarboxylic acids and salts Phosphates

*Few Admixtures can be classified by function as follows:*

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Coloring admixtures
11. Miscellaneous admixtures such as workability, bonding, damp proofing, permeability reducing, grouting, gas-forming, anti washout, foaming, and pumping admixtures



Portland Cement



Coarse Aggregate



Fine Aggregate



Chemical Admixtures

### Properties of concrete

- Density :  $2240 - 2400 \text{ kg/m}^3$
- Compressive strength:  $20 - 40 \text{ MPa}$
- Flexural strength:  $3 - 5 \text{ MPa}$
- Tensile strength:  $2 - 5 \text{ MPa}$
- Modulus of elasticity :  $14000 - 41000 \text{ MPa}$
- Permeability:  $1 \times 10^{-10} \text{ cm/sec}$
- Coefficient of thermal expansion:  $10^{-5} \text{ } ^\circ\text{C}$
- Drying shrinkage:  $4 - 8 \times 10^{-4}$
- Drying shrinkage of reinforced concrete:  $2 - 3 \times 10^{-4}$
- Poisson's ratio :  $0.20 - 0.21$
- Shear strength :  $6 - 17 \text{ MPa}$
- Specific heat capacity :  $0.75 \text{ kJ/kg K}$

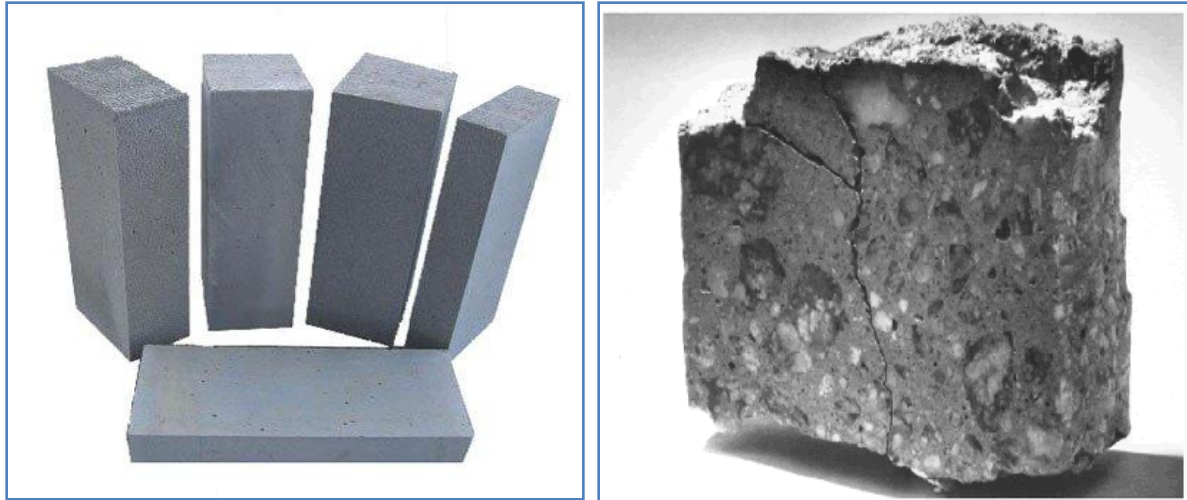
### Factors affecting Strength of concrete

1. **Water-Cement ratio** - It is water cement ratio that basically governs the property of strength. Lesser the water cement ratio, greater will be strength
2. **Type of cementing material** – It affects the hydration process and therefore strength of concrete.
3. **Amount of cementing material** - It is the paste that holds or binds all the ingredients. Thus greater amount of cementing material greater will be strength.
4. **Type of aggregate** - Rough and angular aggregates are preferable as they provide greater bonding.
5. **Air content** – The amount of air improves the concrete resistance on freezing and thawing. But in excess lead to failure
6. **Admixtures** - Chemical admixtures like plasticizers reduce the water cement ratio and increase the strength of concrete at same water cement ratio. Mineral admixtures affect the strength at later stage and increase the strength by increasing the amount of cementing material.

Once the mixing was completed the mixture is said to be **Fresh concrete** which is in plastic state and can be moulded in any forms whereas the **Hardened concrete** is the one which is fully cured.



***Fresh concrete***



*Hardened concrete*

### **FRESH CONCRETE**

**Fresh concrete** is that stage of concrete in which concrete can be moulded in its plastic state. This is also called Green Concrete. Another term used to describe the state of fresh concrete is consistence, which is the ease with which concrete will flow. ***It is the concrete phase from time of mixing to end of time concrete surface finished in its final location in the structure***

For fresh concrete to be acceptable, it should:

1. Be easily mixed and transported.
2. Be uniform throughout a given batch and between batches.
3. Be of a consistency so that it can fill completely the forms for which it was designed.
4. Have the ability to be compacted without excessive loss of energy.
5. Not segregate during placing and consolidation.
6. Have good finishing characteristics.

### **PROPERTIES OF FRESH CONCRETE**

#### **1. Workability of Concrete – Consistency and Cohesiveness**

- i. *Consistency* (Easy flow of concrete) - Slump test, Compacting factor test, Vebe test and Flow table test
- ii. *Cohesiveness* - Segregation and Bleeding

#### **2. Setting**

#### **3. Air entrainment**

**Workability of Concrete** - The capability of being handled and flows into formwork or around any reinforcement, with assistance of compacting equipment. The higher workability concretes are easier to place and handle but obtaining higher workability by increasing water content decreases strength and durability. Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation.

It is obvious that no single test can evaluate all these factors. In fact, most of these cannot be easily assessed even though some standard tests have been established to evaluate them under specific conditions.

**Consistence** is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concrete, but concrete of same consistence may vary in workability. Because the strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under the given conditions. Presence of voids in concrete reduces the density and greatly reduces the strength: 5% of voids can lower the strength by as much as 30%.

To determine the consistency in workability four tests are followed;

- Slump test
- Compacting factor test
- Vee Bee test and
- Flow table test

### **Slump Test**

This test is performed to check the consistency of freshly made concrete. The slump test is done to make sure a concrete mix is workable. The measured slump must be within a set range, or tolerance, from the target slump.

*Workability* of concrete is mainly affected by consistency i.e. wetter mixes will be more workable than drier mixes, but concrete of the same consistency may vary in workability. It can also be defined as the relative plasticity of freshly mixed concrete as indicative of its workability.

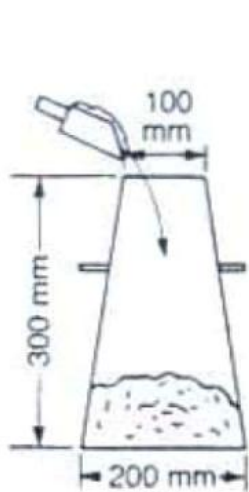
**Tools and apparatus used for slump test (equipment):**

1. Standard slump cone (100 mm top diameter x 200 mm bottom diameter x 300 mm high)
2. **Small scoop**
  1. Bullet-nosed rod (600 mm long x 16 mm diameter)
3. **Rule**
  1. Slump plate (500 mm x 500 mm)

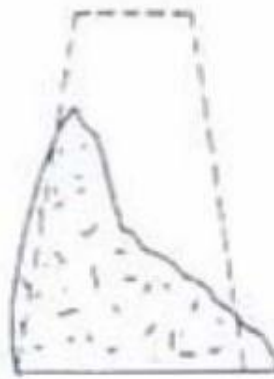
**Procedure of slump test for concrete:**

1. Clean the cone. Dampen with water and place on the slump plate. The slump plate should be clean, firm, level and non-absorbent. Collect a sample of concrete to perform the slump test.
2. Stand firmly on the foot pieces and fill 1/3 the volume of the cone with the sample. Compact the concrete by 'rodding' 25 times. Rodding means to push a steel rod in and out of the concrete to compact it into the cylinder, or slump cone. Always rod in a definite pattern, working from outside into the middle.
3. Now fill to 2/3 and again rod 25 times, just into the top of the first layer.
4. Fill to overflowing, rodding again this time just into the top of the second layer. Top up the cone till it overflows.
5. Level off the surface with the steel rod using a rolling action. Clean any concrete from around the base and top of the cone, push down on the handles and step off the foot pieces.
6. Carefully lift the cone straight up making sure not to move the sample.
7. Turn the cone upside down and place the rod across the up-turned cone.
8. Take several measurements and report the average distance to the top of the sample. If the sample fails by being outside the tolerance (ie the slump is too high or too low), another must be taken. If this also fails the remainder of the batch should be rejected.

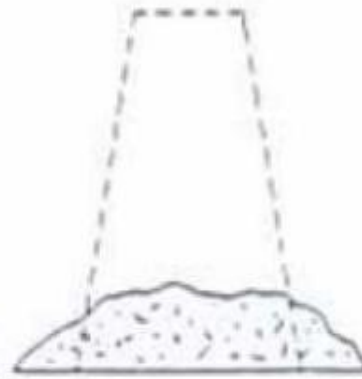




**True**  
Valid slump  
measurement  
0-175 mm



**Shear**  
Mixes having  
tendency to  
segregate –  
repeat test



**Collapse**  
Slumps greater than  
175 mm - self-leveling  
concrete





1. Stand on the two foot pieces of cone to hold in firmly in the place during Steps 1 through 4. Fill cone mold 1/3 full by volume [2-5/8" (67 mm) high] with the concrete sample and rod it with 25 strokes using a round, straight steel rod of 5/8" (16 mm) diameter x 24" (600 mm) long with a hemispherical tip end. Uniformly distribute strokes over the cross section of each layer. For the bottom layer, this will necessitate inclining the rod slightly and making approximately half the strokes near the perimeter (out edge), then progressing with vertical strokes spirally toward the center.



2. Fill cone 2/3 full by volume (half the height) and again rod 25 times with rod just penetrating into, but not through, the first layer. Distribute strokes evenly as described in Step 1.



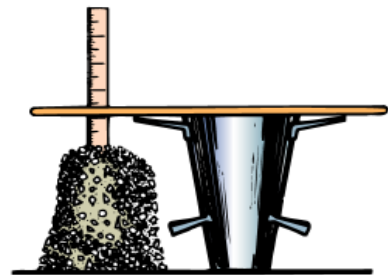
3. Fill cone to overflowing and again rod 25 times with rod just penetrating into, but not through, the second layer. Again distribute strokes evenly.



4. Strikes off excess concrete from top of cone with the steel rod so the cone is exactly level full. Clean the overflow away from the base of the cone mold.



5. Immediately after completion of Step 4, the operation of raising the mold shall be performed in  $5 \pm 2$  sec. by a steady upward lift with no lateral or torsional motion being imparted to the concrete. The entire operation from the start of the filling through removal of the mold shall be carried out without interruption and shall be completed within an elapsed time of 2-1/2 minutes



6. Place the steel rod horizontally across the inverted mold so the rod extends over the slumped concrete. Immediately measure the distance from bottom of the steel rod to the displaced original center of the specimen. This distance, to the nearest 1/4 inch (6 mm), is the slump of the concrete. If a decided falling away or shearing off concrete from one side or portion of the mass occurs, disregard the test and make a new test on another portion of the sample.

### *Slump Cone test and apparatus*

### **Compacting factor test**

Compacting factor of fresh concrete is done to determine the workability of fresh concrete by compacting factor test as per IS: 1199 – 1959. The apparatus used is Compacting factor apparatus.

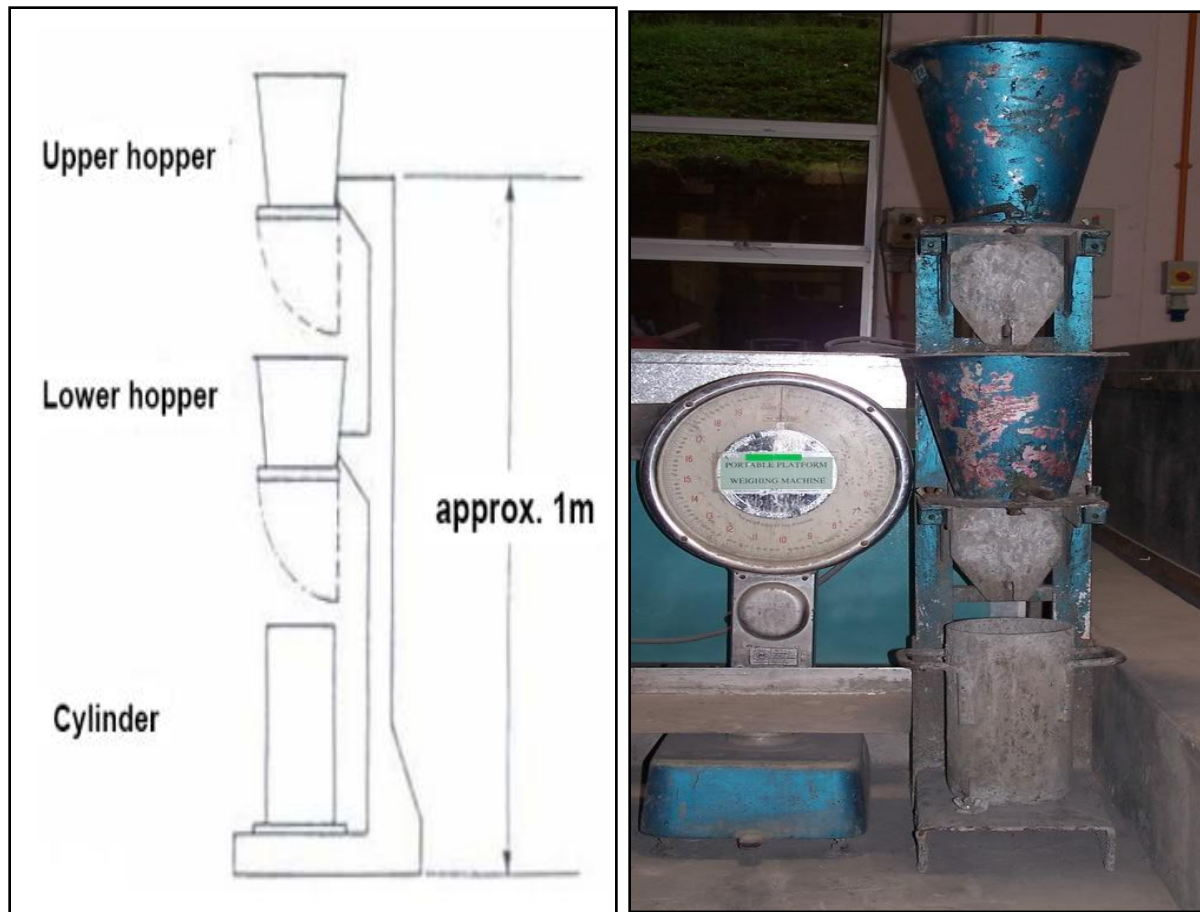
#### ***Procedure***

- The sample of concrete is placed in the upper hopper up to the brim.
- The trap-door is opened so that the concrete falls into the lower hopper. The trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.
- The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades
- The concrete in the cylinder is weighed. This is known as weight of partially compacted concrete.
- The cylinder is filled with a fresh sample of concrete and vibrated to obtain full compaction. The concrete in the cylinder is weighed again. This weight is known as the weight of fully compacted concrete.

**Compacting factor = (Weight of partially compacted concrete)/(Weight of fully compacted concrete)**

$$= (W_1 - W_2 / W_2 - W)$$

**NOTE:** The test is sufficiently sensitive to enable difference in work ability arising from the initial process in the hydration of cement to be measured. Each test, there for should be carried out at a constant time interval after the mixing is completed, if strictly comparable results are to be obtained. Convenient time for releasing the concrete from the upper hopper has been found to be two minutes after the completion of mixing.



*Compaction factor apparatus*

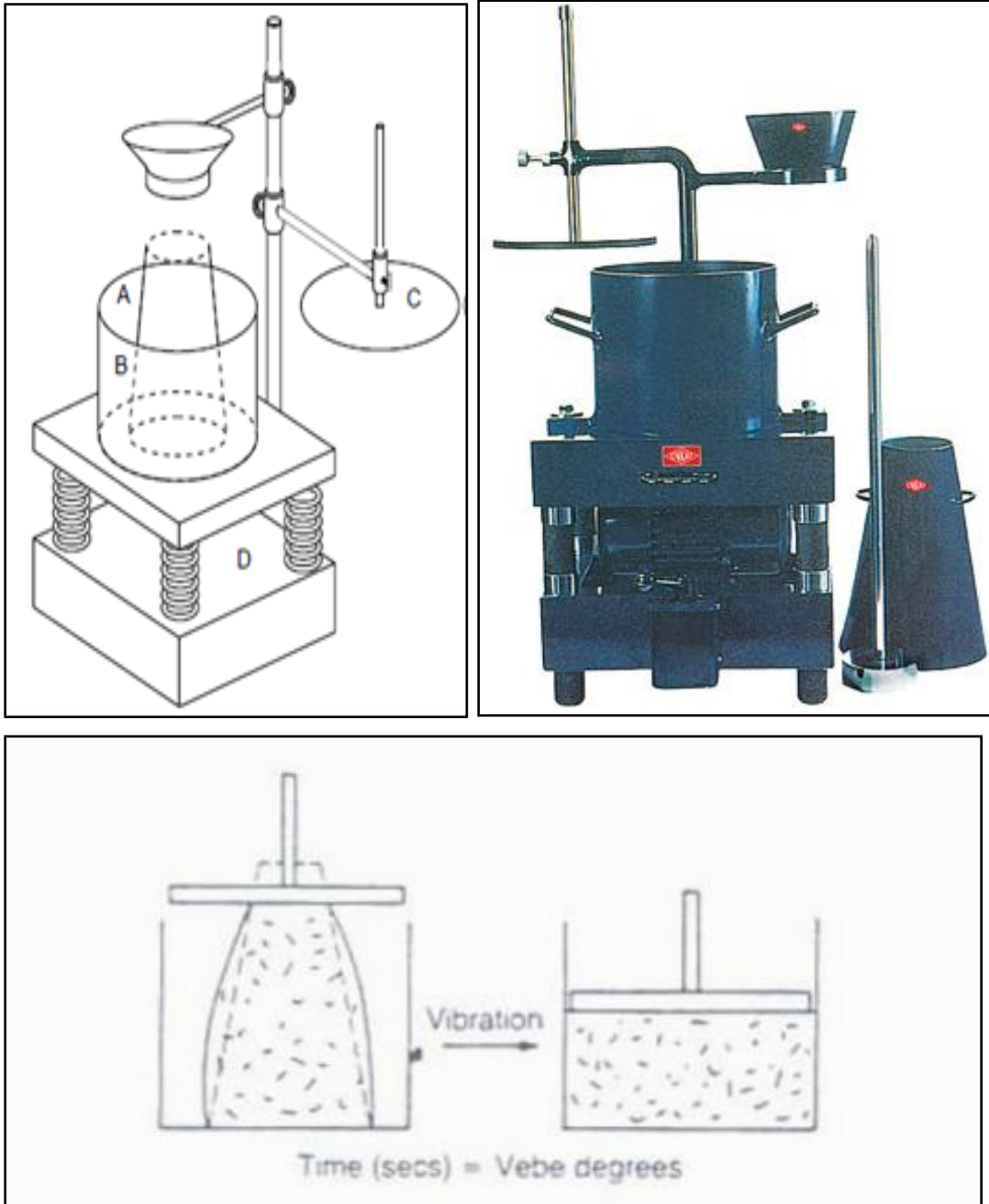
### **Vee Bee test**

To determine the workability of fresh concrete by using a Vee-Bee consistometer as per IS: 1199 – 1959. The apparatus used is Vee-Bee consistometer.

### ***Procedure***

- A conventional slump test is performed, placing the slump cone inside the cylindrical part 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 switched on and a stop-watch is started, simultaneously. Vibration is continued till the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.

- When the concrete fully assumes a cylindrical shape, the stop-watch is switched off immediately. The time is noted.
- The consistency of the concrete should be expressed in VB-degrees, which is equal to the time in seconds recorded above.



*Vee Bee test apparatus*

## **Flow table test**

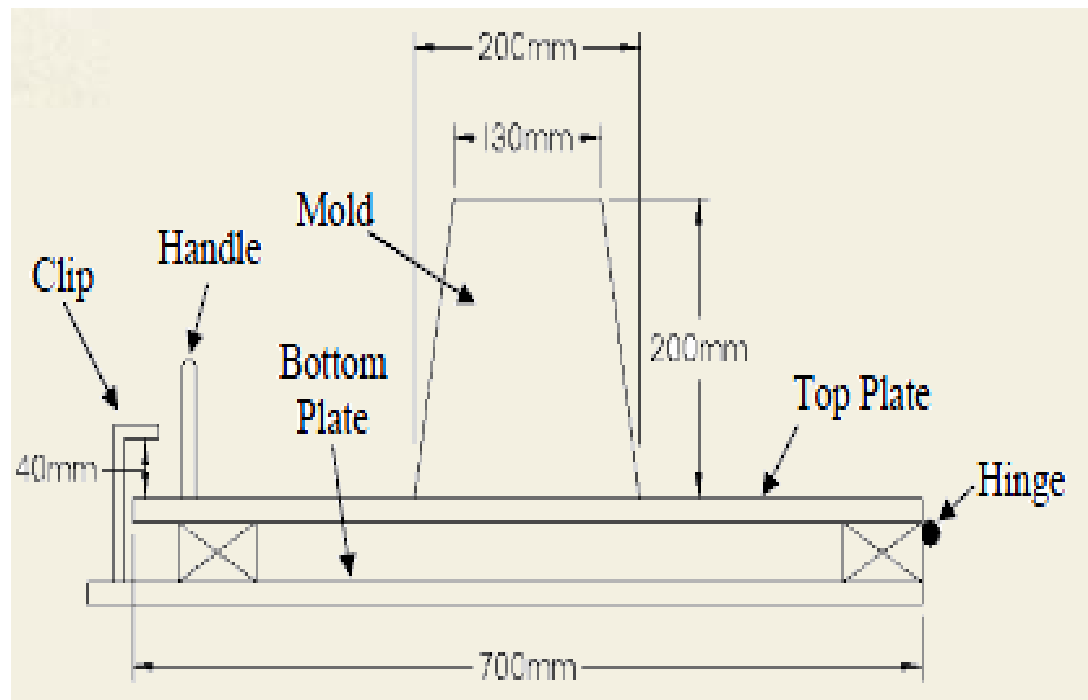
To determine the workability of fresh concrete by using a Flow table test as per IS: 5512 – 1983. The apparatus used is Flow table apparatus.

### ***Procedure***

- The 700 mm square flow table is hinged to a rigid base, provided with a stop that allows the far end to be raised by 40 mm.
- A cone, similar to that used for slump testing but truncated, is filled with concrete in two layers.
- Each layer is tamped 10 times with a special wooden bar and the concrete of the upper layer finished off level with the top of the cone. Any excess is cleaned off the outside of the cone.
- The cone is then raised allowing the concrete to flow out and spread out a little on the flow table.
- The table top is then raised until it meets the stop and allowed to drop freely 15 times.
- This causes the concrete to spread further, in a roughly circular shape.
- The flow diameter is the average of the maximum diameter of the pool of concrete and the diameter at right angles.

**Flow = final diameter of the concrete  
(mean of two measurements at right angles)**

As well as getting an accurate measurement of the workability of the concrete, the flow test gives an indication of the cohesion. A mix that is prone to segregation will produce a non-circular pool of concrete. Cement paste may be seen separating from the aggregate. If the mix is prone to bleeding, a ring of clear water may form after a few minutes.



*Flow table test apparatus*

## **Segregation and Bleeding**

**SEGREGATION** – It can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. 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.

***Segregation may be of three types:***

1. Coarse aggregate separating out or settling down from the rest of the matrix.
2. Paste separating away from coarse aggregate.
3. Water separating out from the rest of the material being a material of lowest specific gravity.

A well made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time; the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients.

***The conditions favorable for segregation are***

1. Badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates.
2. Insufficiently mixed concrete with excess water content.
3. Dropping of concrete from heights as in the case of placing concrete in column concreting.
4. When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades.
5. 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. If 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 optimum 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.



### ***Segregation***

**BLEEDING** – This in concrete 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, 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**. In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season.

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 un segmented. These 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 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 re vibration 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.

### **Prevention of Bleeding in concrete**

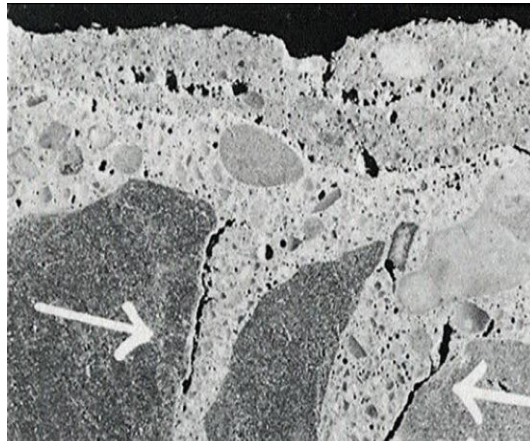
- Bleeding can be reduced by proper proportioning and uniform and complete mixing.
  - Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse.
  - Air-entraining agent is very effective in reducing the bleeding.
  - Bleeding can be reduced by the use of finer cement or cement with low alkali content.
- Rich mixes are less susceptible to bleeding than lean mixes.

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 well to the concrete.

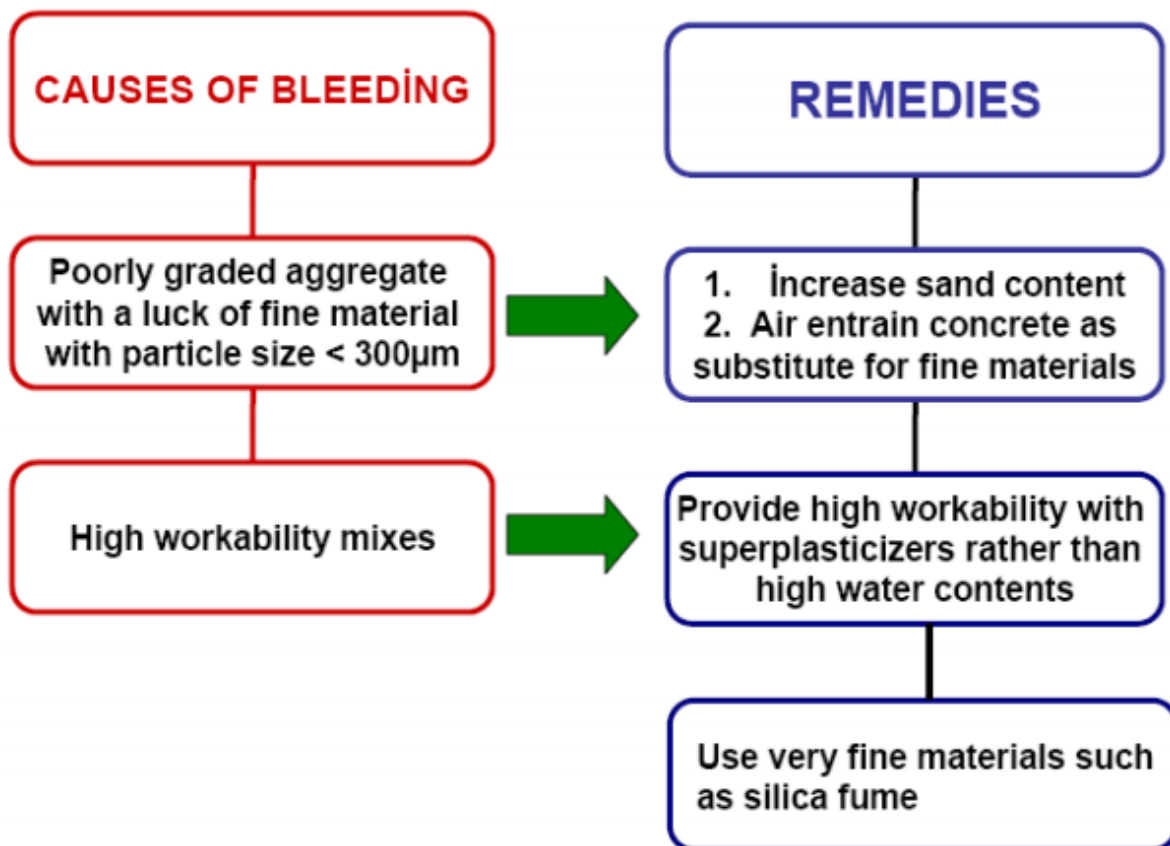


In early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its

plasticity, which causes undue harm to the concrete. Controlled re vibration may be adopted to overcome the bad effect of bleeding.



*Bleeding in concrete*



### **Factors affecting concrete workability**

1. Water-Cement ratio
2. Amount and type of Aggregate
3. Amount and type of Cement
4. Weather conditions
  - a. Temperature
  - b. Wind
5. Chemical Admixtures
6. Sand to Aggregate ratio

**Water content or Water Cement Ratio** - More the water cement ratio more will be workability of concrete. Since by simply adding water the inter particle lubrication is increased. High water content results in a higher fluidity and greater workability but reduces the strength of concrete. Because with increasing w/c ratio the strength decreases as more water will result in higher concrete porosity. So, the lower the w/c, the lower is the void volume/solid volume, and the stronger the hardened cement paste. Increased water content also results in bleeding, hence, increased water content can also mean that cement slurry will escape through the joints of the formwork (Shuttering).

**Amount and type of Aggregate** - Since larger Aggregate sizes have relatively smaller surface areas (for the cement paste to coat) and since less water means less cement, it is often said that one should use the largest practicable Aggregate size and the stiffest practical mix. Most building elements are constructed with a maximum Aggregate size of 3/4" to 1", larger sizes being prohibited by the closeness of the reinforcing bars. Because concrete is continuously shrinking for years after it is initially placed, it is generally accepted that under thermal loading it will never expand to its originally-placed volume. More the amount of aggregate less will be workability. Using smooth and round aggregate increases the workability. Workability reduces if angular and rough aggregate is used. Greater size of Aggregate- less water is required to lubricate it, the extra water is available for workability. Angular aggregates increases flakiness or elongation thus reduces workability. Round smooth aggregates require less water and less lubrication and greater workability in a given w/c ratio. Porous aggregates require more water compared to non absorbent aggregates for achieving same degree of workability.

**Aggregate Cement ratio** - More the ratio less the workability. Since less cement mean less water, so the paste is stiff.

### **Weather Conditions**

(a) **Temperature** - If temperature is high, evaporation increases, thus workability decreases.

(b) **Wind** - If wind is moving with greater velocity, the rate of evaporation also increase reduces the amount of water and ultimately reducing workability.

**Admixtures** - Chemical admixtures can be used to increase workability. Use of air entraining agent produces air bubbles which acts as a sort of ball bearing between particles and increases mobility, workability and decreases bleeding, segregation. The use of fine pozzolanic materials also has better lubricating effect and more workability.

**Sand to Aggregate ratio** - If the amount of sand is more the workability will reduce because sand has more surface area and more contact area causing more resistance. The ingredients of concrete can be proportioned by weight or volume. The goal is to provide the desired strength and workability at minimum expense. A low water-cement ratio is used to achieve a stronger concrete. It would seem therefore that by keeping the cement content high one could use enough for good workability and still have a low w/c ratio.

**Setting of concrete** - The hardening of concrete before its hydration is known as setting of concrete. The hardening of concrete before it gains strength. The transition process of changing of concrete from plastic state to hardened state is also setting of concrete. Setting of concrete is based or related to the setting of cement paste. Thus cement properties greatly affect the setting time.

### **Factors affecting setting**

- Water Cement ratio
- Suitable Temperature
- Cement content
- Type of Cement

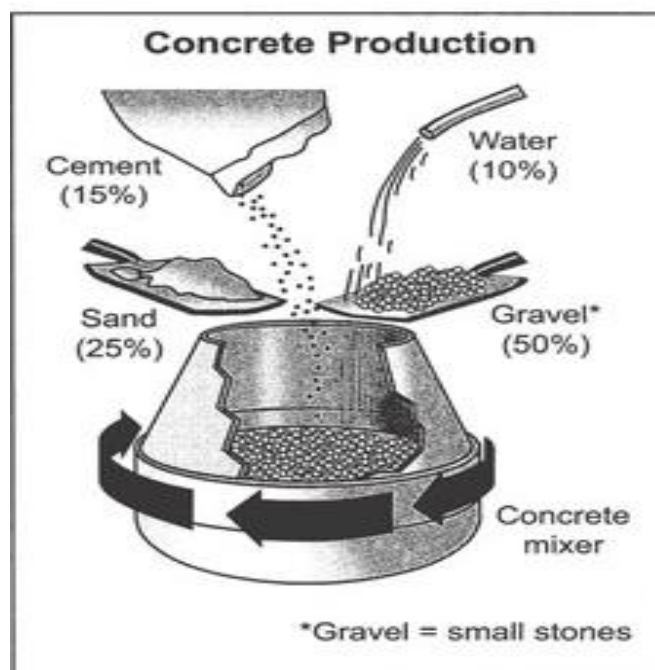
- Fineness of Cement
- Relative Humidity
- Admixtures
- Type and amount of Aggregate

**Air Entrainment** - It reduces the density of concrete and consequently reduces the strength. Air entrainment is used to produce a number of effects in both the plastic and the hardened concrete. These include

1. Resistance to freeze–thaw action in the hardened concrete.
2. Increased cohesion, reducing the tendency to bleed and segregation in the plastic concrete.
3. Compaction of low workability mixes including semi-dry concrete.
4. Stability of extruded concrete.
5. Cohesion and handling properties in bedding mortars.

### **MANUFACTURING OF CONCRETE**

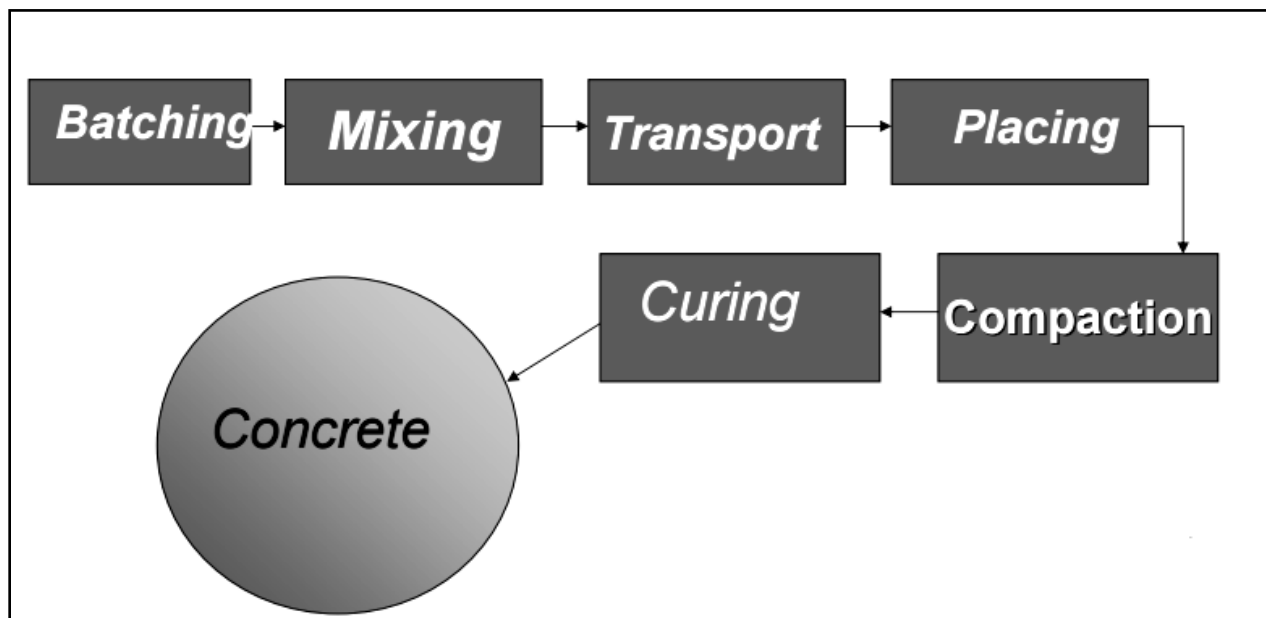
It is interesting to note that the ingredients of good concrete and bad concrete are the same. If particular care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage, it will result in good concrete.



*General concrete production*

The various stages of manufacture of concrete are:

1. **Batching**
2. **Mixing**
3. **Transporting**
4. **Placing**
5. **Compacting**
6. **Curing**
7. **Finishing**



*Process of concrete manufacturing*

**1. BATCHING** is the process of measurement of specified quantities of cement, aggregates, water and admixture, i.e., ingredients of concrete in correct proportion.

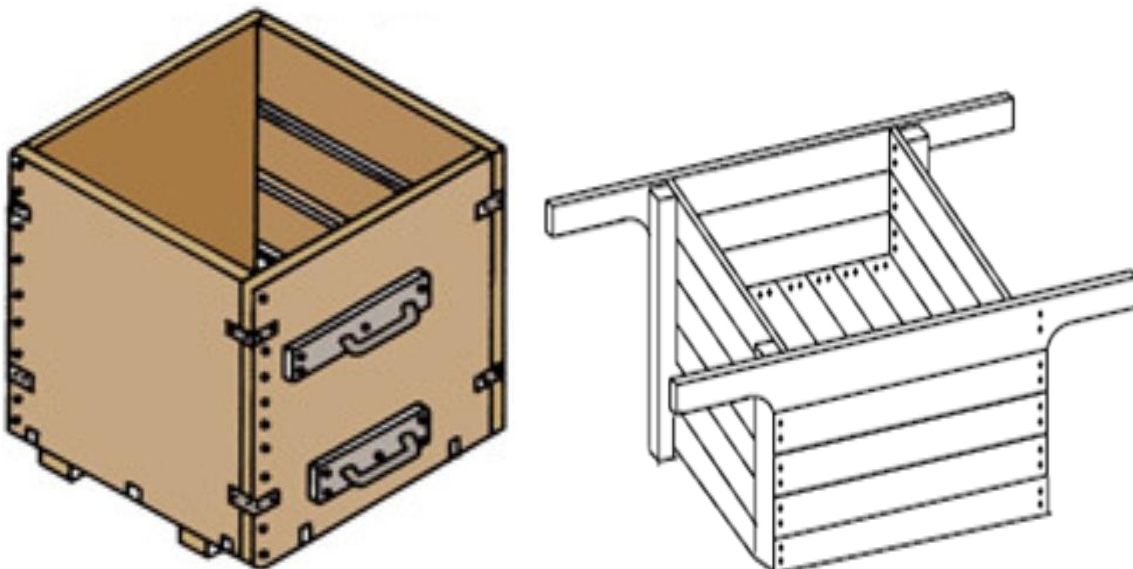
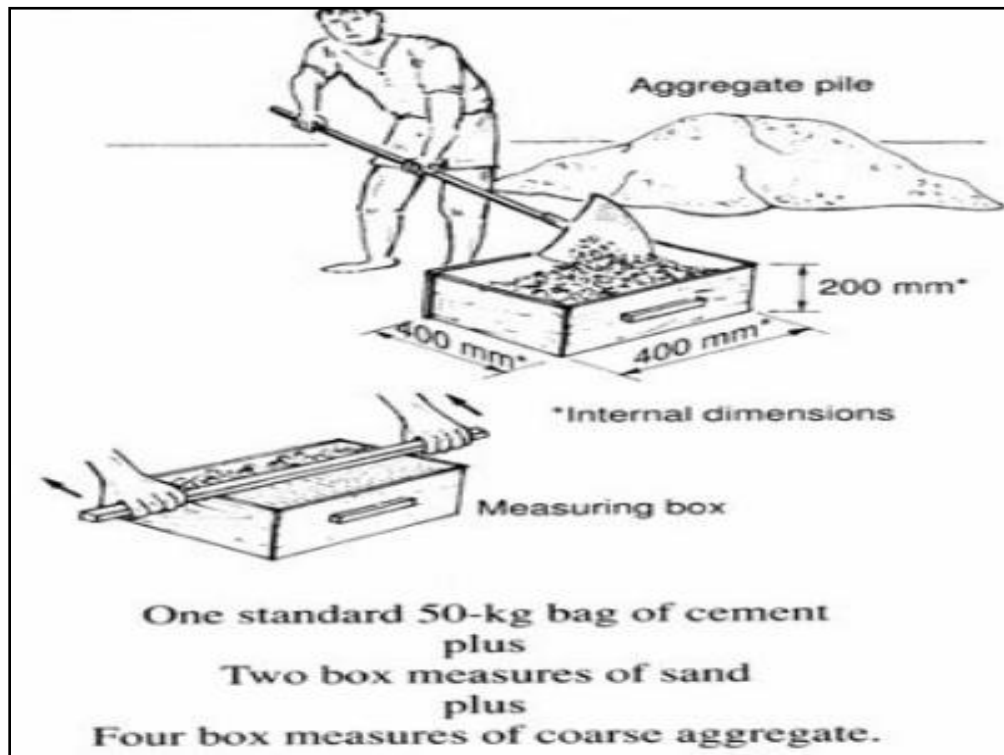
***Batching Process***

- Volumetric batching (Not desirable except for small non engineered jobs)
- Weigh Batching

**Volumetric batching** – It is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The effect of



bulking should be considered for moist fine aggregate. For unimportant concrete or for any small job, concrete may be batched by volume.



*Volumetric batching*

**Weigh Batching** - Weigh batching is the correct method of measuring the materials. Use of weight system in batching, facilitates accuracy, flexibility and simplicity. Large weigh batching

plants have automatic weighing equipment. On large work sites, the weigh bucket types of weighing equipments are used.

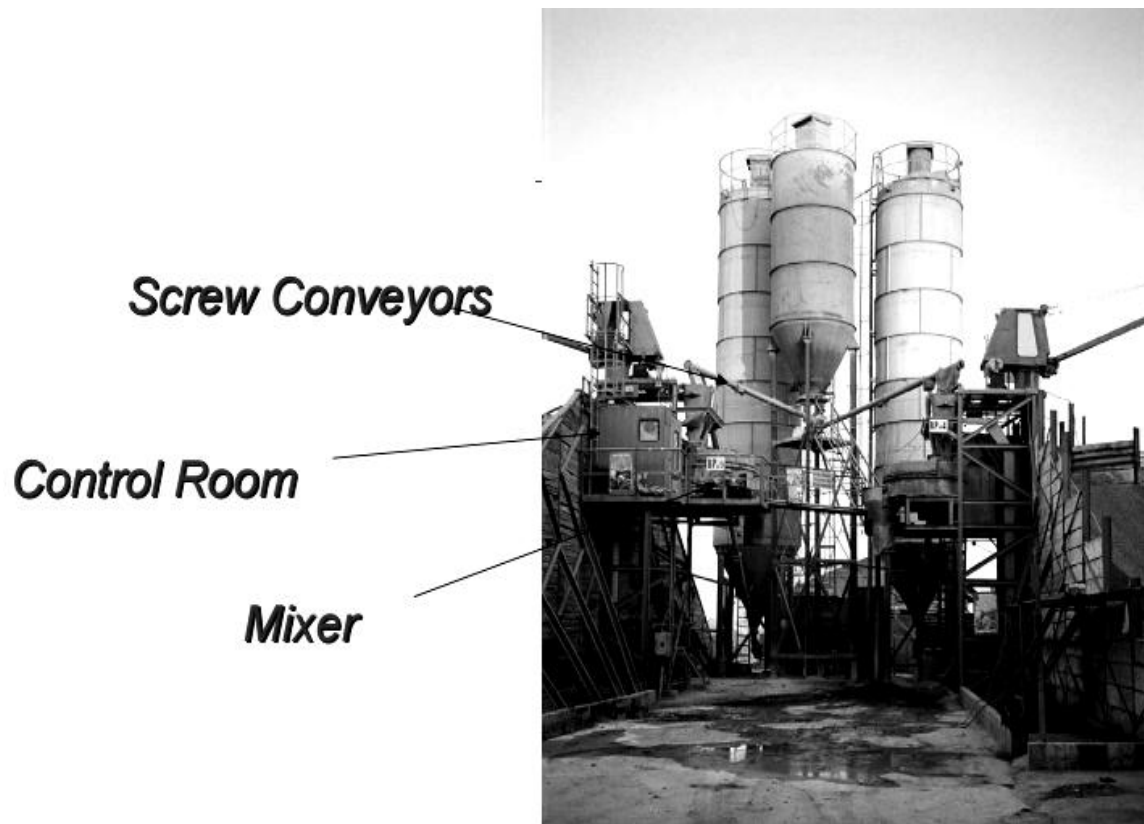


***Weigh batching***

#### *Components of a Batching Plant*

- Aggregate bins for various types of aggregates
- Feeding mechanisms such as scrapers, conveyors or hoists etc. to transfer aggregate to scales (balances)
- Balance and measuring system
- Cement silos and a conveyor screw or bucket conveyor
- The storage tank for water and water measuring system
- Dispenser for chemical (liquid) admixture





***Batching plant***

**2. MIXING** - Thorough mixing is essential for production of uniform quality concrete. The equipment and method should be capable of effectively mixing concrete material containing largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work.

**Types**

1. Manual mixing or Hand mixing
2. Stationary mixing
3. Ready mix concrete

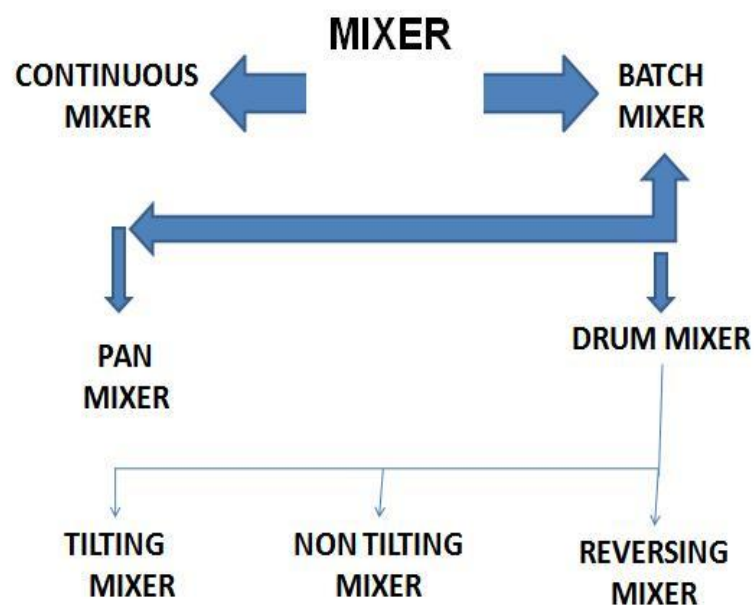
**Manual or hand mix** - Hand mixing is practiced for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method. Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. It is spread out by 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 color is achieved. Water is taken in a water-can fitted 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.



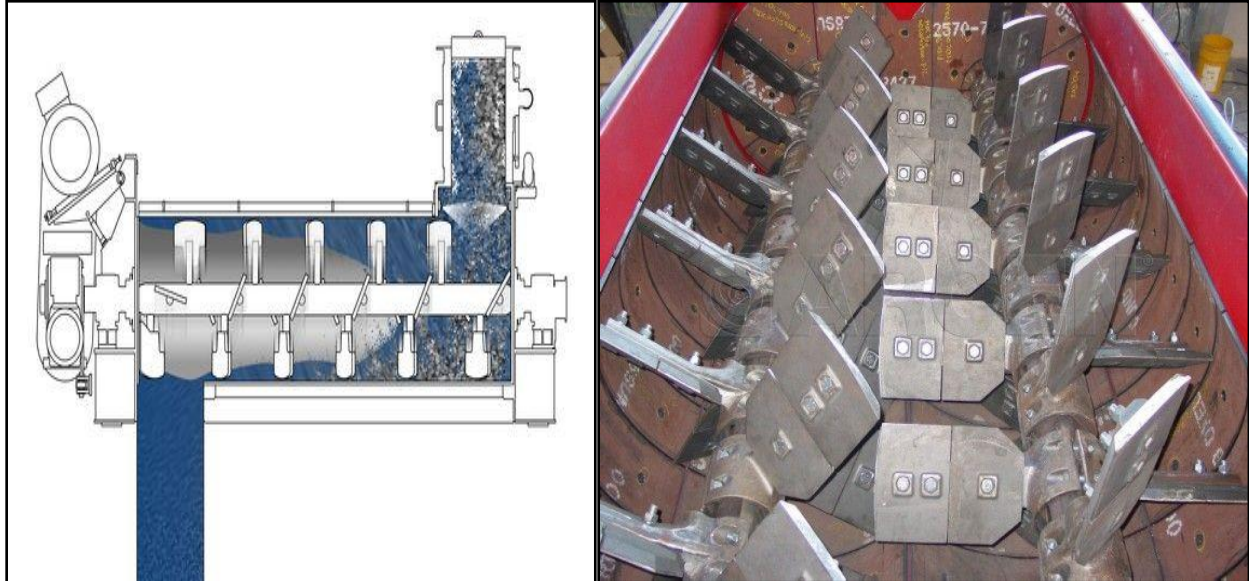
*Manual mixing of concrete*

**Stationary 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. The following schematic sketch shows the type of stationary mixes.





**Continuous Mixer** - Continuous type mixer produces concrete at a constant rate. In this type, the constituents are continuously entered at one end as the fresh concrete exits the other end. They are usually non-tilting drums with screw-type blades rotating in the middle of the drum.



*Traditional Continuous Mixer*

**Batch Mixer** - The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer.

Two main types of batch mixer can be distinguished by the orientation of the axis of rotation.

1. Horizontal or Inclined (drum mixers)
2. Vertical (pan mixers)

The drum mixers have a drum, with fixed blades, rotating around its axis, while the pan mixers may have either the blades or the pan rotating around the axis.

**Horizontal or Inclined or Drum Mixers** - This is also called as free fall mixer or gratify mixer. In this type of mixer, concrete is mixed by lifting the ingredients with the help of fixed blades inside a rotating drum and then dropping the material by overcoming the friction between the mixture and the blades. The drum of the mixer can be filled and emptied by changing its direction of rotation, opening it, or tipping it up. Rotation speed must carefully follow machine-specific instructions and should not be too fast so that the free fall of the mixture is not interrupted by the centrifugal force.

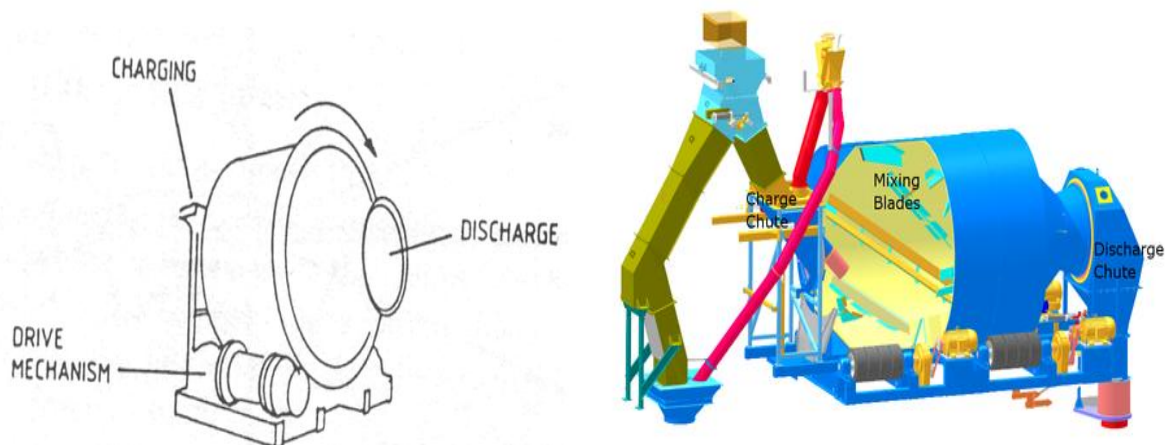


*Horizontal batch mixer*

## Types of Drum Mixers

- Non-tilting drum mixer.
- Reversing drum mixer.
- Tilting drum mixer.

**Non-tilting drum mixer** - The non-tilting drum mixer implies that the orientation of the drum is fixed. The materials are added at one end and discharged at the other. A non tilting drum mixer is one in which the axis of the mixer is always horizontal, and discharge takes place by inserting a chute into the drum or by reversing the direction of rotation of drum. Because of slow rate of discharge, some segregation may occur. There are two openings, one at each end of the drum: one for feeding the ingredients, the other for discharging the mixture.

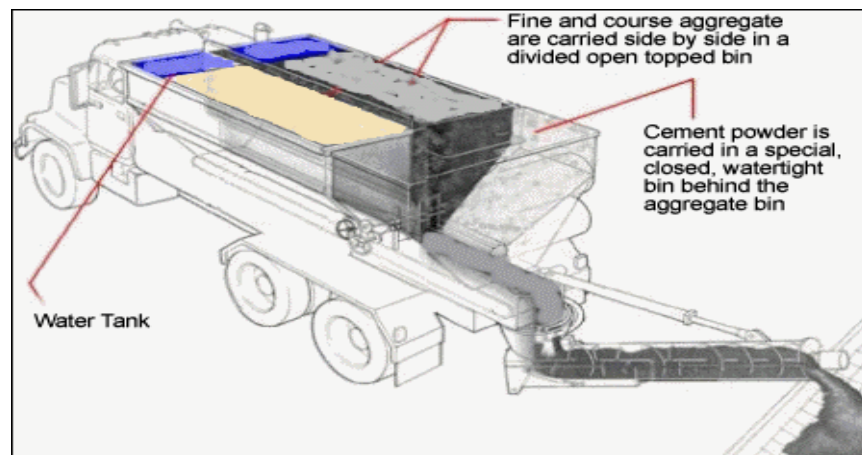




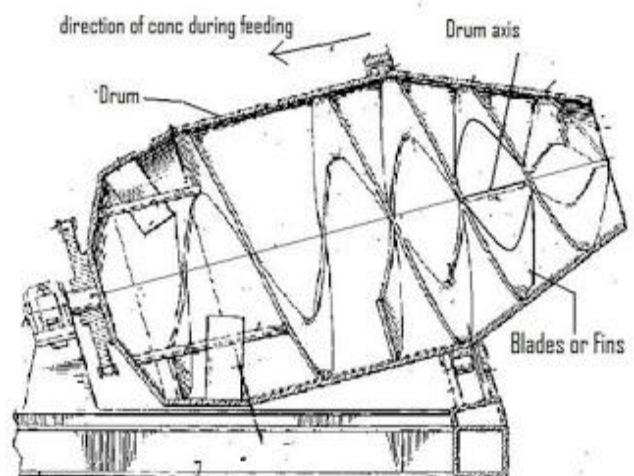
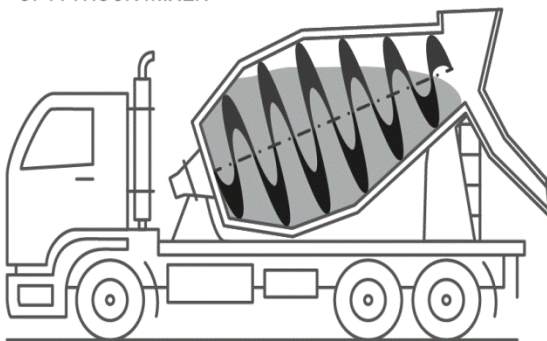
*Non tilting drum mixer*

**Reversing drum mixer (truck mixer)** - The reversible drum mixer is similar to the non tilting mixer except that the same opening is used to add the constituents and to discharge the aggregate. The drum on a reversible mixer has one horizontal axis around which it rotates. In mixing position, the drum rotates in one direction; while for discharging, the rotation is reversed. Commonly self-loading, reversible mixers are mid-size to large-size units mounted on a two-or four-wheeled trailer for transportation between sites. The mixer is equipped with a tilting hopper similar to that occasionally found on a tilting mixer, or with a hoist-like hopper that moves up and down on a short inclined set of rails and that dumps the ingredients through a bottom opening into the drum. A built-in mechanical skip to facilitate aggregate loading into the hopper is optional on many models. Most models of this mixer type are equipped with a water tank and meter, and optionally (the larger models) with a built-in aggregates batcher.





### OPERATION OF A TRUCK MIXER



### Types of reversing or truck Mixers

- Rear discharge truck mixers
- Front discharge truck mixers

**Rear discharge trucks** - Rear discharge trucks require both a driver and a "chute man" to guide the truck and chute back and forth to place concrete in the manner suitable to the contractor.



***Rear discharge trucks***

**Front discharge trucks** - Newer front discharge trucks have controls inside the cab of the truck to allow the driver to move the chute in all directions.



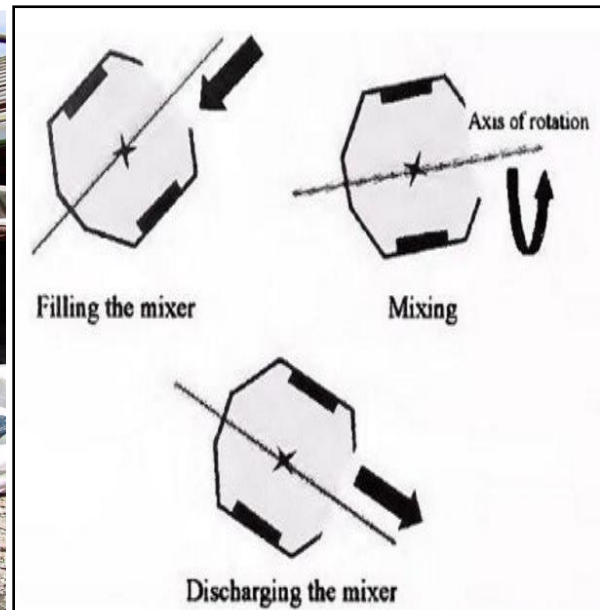
***Front discharge trucks***

**Tilting mixer** - In this type of mixer axis of the drum does not remain horizontal. The position of drum axis for different operations i.e. feeding, mixing and discharge is different. Tilting mixers are usually trailer-mounted or otherwise portable, small to mid-size mixers, used either as main concrete mixing equipment on small sites or as ancillary equipment on sites served by concrete plant.

The drum has two axes: one around which the drum rotates and another that serves to change from loading and mixing position (drum opening up) to discharging position (drum



opening down). This position change is done manually by a dump wheel (or handle, in the smaller mixers), while drum rotation is electric, gasoline, or diesel powered. Drums are traditionally made of steel, but polyethylene drums for easier cleaning are now offered. Most mixers are of the side-dump type, but end-dump mixers are also manufactured. Material is generally loaded manually, directly into the drum. There are larger-size self-loading units equipped with a tilting hopper. After being filled manually at ground level, the hopper is tilted up mechanically and dumps the material into the drum. A built-in mechanical drag shovel to facilitate aggregate loading into the hopper is optional in some models. The drum is conical or bowl shaped with internal vanes and the discharge is rapid and unsegregated so that these mixers are suitable for mixes of low workability and for those containing larger size aggregate. The drum axis usually stays at an angle of 15 degree from horizontal during mixing. Tilt mixer offers consistent mixing with lower operating and maintenance cost. Tilting drum is the most common type of drum mixers for small batches. Tilting mixers can handle larger size aggregates more easily and will discharge mixed concrete rapidly than a non tilting mixer.





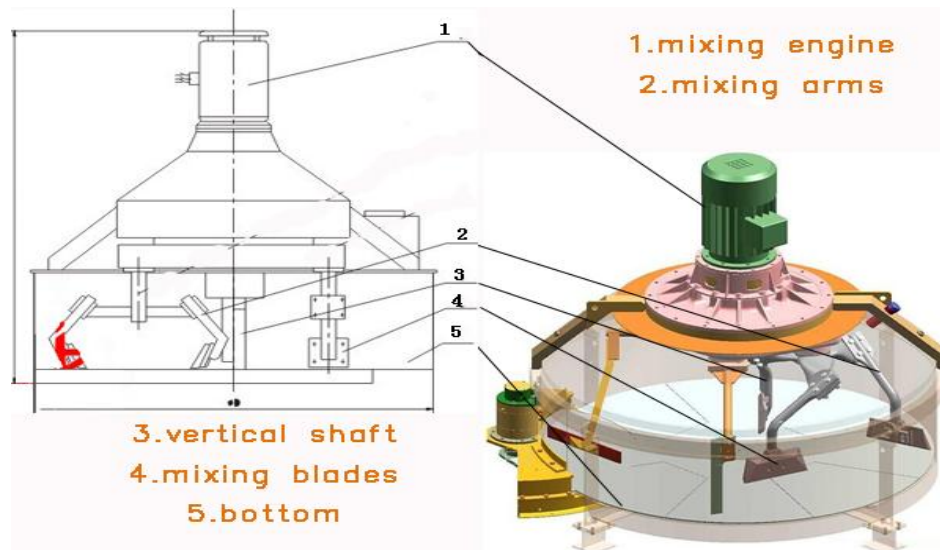
*Tilting drum mixer*

### ***Pan Mixer***

A pan type mixer is a forced-action mixer, as distinct from drum mixer which relies on the free fall of the concrete inside the drum. The pan mixer consist of a circular pan rotating about its axis with one or two stars paddles rotating about vertical axis of pan.

Components of a pan mixer are,

- Pan
- Shaft
- Scraper





***Pan Mixer***

**3. TRANSPORTING** - Transporting the concrete mix is defined as the transferring of concrete from the mixing plant to the construction site. Keep in mind that not all concrete is mixed on the actual construction site and could require some significant travel. This is most common for ready-mixed concretes. The main objective in transporting concrete is to ensure that the water-cement ratio, slump or consistency, air content, and homogeneity are not modified from their intended states.

***Important Factors in Choosing Transportation***

There are many elements of transporting that need to be considered in order to ensure that a mix does not change its state as specified in the contract. The two key goals when transporting concrete from the mixing plant to the construction site are to prevent segregation and to not reduce the workability of the mix. This transportation process must be well thought out and organized efficiently. As a general rule of thumb, thirty to sixty minutes of transportation are acceptable on small jobs. At a central or portable ready-mix plant, concrete should be discharged from a truck mixer or agitator truck within two hours. If non-agitating transporting equipment is used, this time is reduced to one hour. All delays must be avoided in order prevent honeycombing.

Many factors determine which type of transportation is most suitable. Type and constituents of the concrete mix, size and type of construction, topography, weather conditions (i.e. temperature, humidity, wind speed), location of the batch plant, and cost are all taken into consideration when



choosing a mode of transport for your concrete. If you choose the wrong mode of transportation, your concrete could be segregated, which would in effect, make it useless. Therefore it is essential that adequate thought be given to the type of transportation you actually need.

### ***Categories of Transportation***

There are many modes of transportation as shown below:

- a) Mortar Pan - It is a labor intensive method and generally used for small works. There are no chances of segregation of concrete. In hot weather, there is a substantial loss of water due to more exposure of concrete to environment.



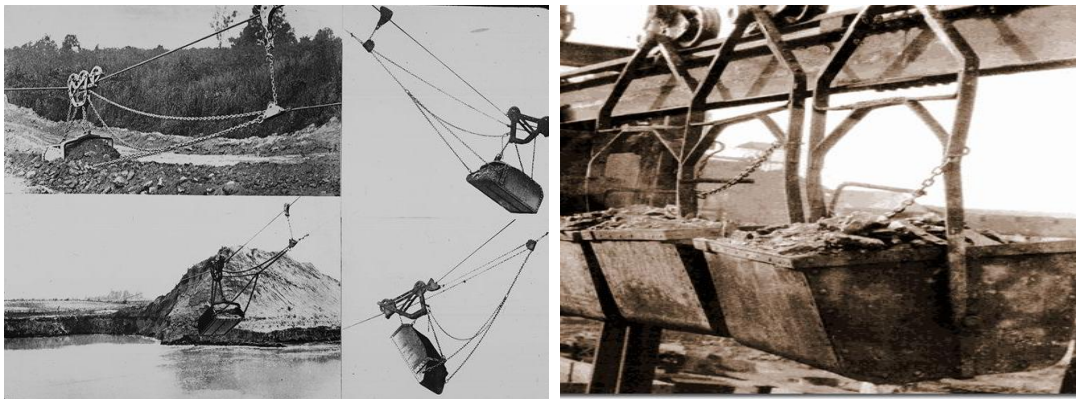
- b) Wheelbarrow or Hand cart - It is normally used on ground level i.e. road construction and other similar structures. Segregation can occur if transportation is done on rough roads, however this problem can be minimized if pneumatic tyres are used.



- c) Truck mixer - It is an improved and better method for long lead concreting. The concrete is covered with tarpaulin if it is transported in open trucks. If long distance is involved, agitators should be used.



- d) Bucket or Ropeway - It is suitable for works in valley, over high piers and long dam sites. Excessive free fall of concrete should be avoided to minimize segregation.



- e) Chute - It is generally used for concreting in deep locations. Care should be taken that slope should not be flatter than 1V:2.5H, otherwise concrete will not slide down. But workability should not be changed to suit the delivery by chute. Technically it is not a very good method but it is extensively used in the field.





- f) Belt conveyor - It has limited application due to chances of segregation on steep slopes, roller points and changes in direction of belt. It also involves over-exposure of concrete to environment.



- g) Concrete pump - It is the most sophisticated 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 at 8 to 70 cubic meters per hour up to a horizontal distance of 300 meter and vertical distance of 90 meter. Pipe diameter is generally 8 to 20 cm and it is made of steel, plastic or aluminum. The workability for pumped concrete should have a minimum of 40 to 100 mm of slump or 0.90 to 0.95 compacting factor. 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.



- h) Skip and Hoist - It is a widely used method for high rise structures. Concrete is fed into the skip which travels vertically on rails like a lift. After discharging, it is better to turn over the concrete before use to avoid segregation.



- i) Transit Mixer - Transit mixer is one of the most popular equipment for transporting concrete over a long distance particularly in ready mix concrete plant. They are truck mounted having a capacity of 4 to 7 cubic meter. There are two variations. In one, mixed concrete is transported to the site by keeping it agitated all along at a speed varying between 2 to 6 revolutions per minute. In other category, the concrete is batched at the central batching plant and mixing is done in the truck mixer either in transit or immediately prior to discharging concrete at site.



#### 4. PLACING

Before any concrete is placed the entire placing program consisting of equipment, layout, proposed procedures and methods is planned and no concrete is placed until formwork is inspected and found suitable for placement. Equipment for conveying concrete should be of such size and design as to ensure a practically continuous flow of concrete during depositing without segregation of materials considering the size of the job and placement location.

Concrete is placed in its final position before the cement reaches its initial set and concrete is compacted in its final position within 30 minutes of leaving the mixer and once compacted it should not be disturbed.

In all cases the concrete is deposited as nearly as practicable directly in its final position and should not be re-handled or caused to flow in a manner which may cause segregation, loss of materials, displacement of reinforcement, shuttering or embedded inserts or impair its strength. For locations where direct placement is not possible and in narrow forms suitable drop and Elephant Trunks to confine the movement of concrete is provided. Special care is taken where concrete is dropped from a height especially if reinforcement is in the way particularly in columns and thin walls.

Concrete should be placed in the shuttering by shovels or other methods and should not be dropped from a height more than 1 m or handle in a manner which will cause segregation. Concrete placed in restricted forms by borrows; buggies, cars, sort chutes or hand shoveling should be subjected to the requirement for vertical delivery of limited height to avoid segregation and should be deposited as nearly as practicable in its final position.

Concreting once started should be continuous until the pour is completed. Concrete should be placed in successive horizontal layers of uniform thickness ranging from 150 mm to 900 mm. These should be placed as rapidly as practicable to prevent the formation of cold joints or planes of weakness between each succeeding layers within the pour.

The thickness of each layer should be such that it can be deposited before the previous layer has stiffened. The bucket loads or other units of deposit should be spotted progressively along the face of the layer with such overlap as will facilitate spreading the layer to uniform depth and texture with a minimum of shoveling. Any tendency to segregation should be corrected by shoveling stones into mortar rather than mortar onto stones. Such a condition should be corrected by redesign of mix or other suitable means.





*Placing of concrete*

## 5. COMPACTING

Compaction is a process of expelling the entrapped air. If we don't expel this air, it will result into honeycombing and reduced strength. It has been found from the experimental studies that 1% air in the concrete approximately reduces the strength by 6%.

It is important to compact the concrete fully because:

- Air voids reduce the strength of the concrete. For every 1% of entrapped air, the strength falls by somewhere between 5 and 7%. This means that concrete containing a mere 5% air voids due to incomplete compaction can lose as much as one third of its strength.

- Air voids increase concrete's permeability. That in turn reduces its durability. If the concrete is not dense and impermeable, it will not be watertight. It will be less able to withstand aggressive liquids and its exposed surfaces will weather badly.
- Moisture and air are more likely to penetrate to the reinforcement causing it to rust.
- Air voids impair contact between the mix and reinforcement (and, indeed, any other embedded metals). The required bond will not be achieved and the reinforced member will not be as strong as it should be.
- Air voids produce blemishes on struck surfaces. For instance, blowholes and honeycombing might occur.

### ***Different methods of concrete compaction***

There are two methods of compaction adopted in the field as given below.

- Hand compaction
- Mechanical Compaction

#### **HAND COMPACTION**

Hand compaction is used for ordinary and unimportant structures. Workability should be decided in such a way that the chances of honeycombing should be minimum. The various methods of hand compaction are as given below.

1. ***Rodding*** - It is a method of poking with 2m long, 16 mm dia rod at sharp corners and edges. The thickness of layers for rodding should be 15 to 20 cm.



2. **Ramming** - It is generally used for compaction on ground in plain concrete. It is not used either in RCC or on upper floors.



3. **Tamping** - It is a method in which the top surface is beaten by wooden cross beam of cross section 10 cm x 10 cm. both compaction and leveling are achieved simultaneously. It is mainly used for roof slabs and road pavements.

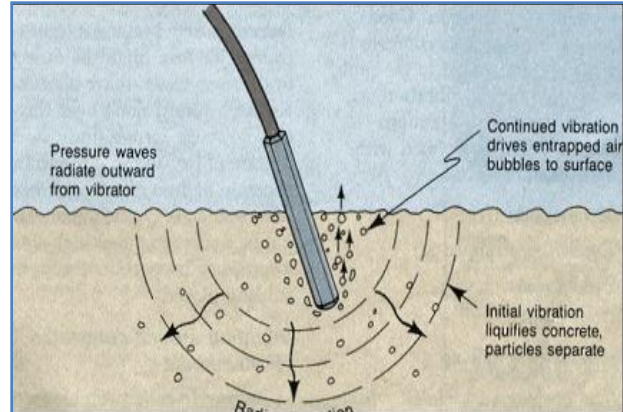


### MECHANICAL COMPACTION

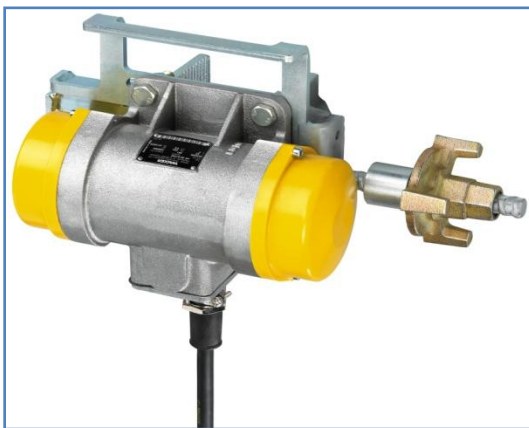
Vibration is imparted to the concrete by mechanical means. It causes temporary liquefaction so that air bubbles come on to the top and expelled ultimately. Mechanical vibration can be of various types as given under.

1. **Internal Vibration** - It is most commonly used technique of concrete vibration. Vibration is achieved due to eccentric weights attached to the shaft. The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. the frequency range adopted is normally 3500 to 5000 rpm. The correct and incorrect methods of vibration using internal vibration needles are shown below.





2. **External Vibration** - This is adopted where internal vibration can't be used due to either thin sections or heavy reinforcement. External vibration is less effective and it consumes more power as compared to the internal vibration. The form work also has to be made extra strong when external vibration is used.



3. **Table Vibration** - It is mainly used for laboratories where concrete is put on the table.



4. **Platform Vibration**- It is similar to table vibrators but these are generally used on a very large scale.
6. **Surface Vibration** - These are also called screed board vibrators. The action is similar to that of tamping. The vibrator is placed on screed board and vibration is given on the surface. It is mainly used for roof slabs, road pavements etc., but it is not effective beyond 15 cm depth.



## External : Surface Vibrators



*Combination of all*

## 7. CURING

Once concrete has been placed and consolidated it must be allowed to cure properly to develop good final properties. As the concrete hardens and gains strength it becomes less and less vulnerable, so the critical time period is the first hours and days after it is placed. Proper curing of concrete generally comes down to two factors, keeping it moist and keeping it supported. Hydration of cement, as the word itself implies, involves reaction with water. To cure properly, the cement paste must be fully saturated with water. If the relative humidity level inside the concrete drops to near 90% the hydration reactions will slow, and by 80% they will stop altogether. Not only will this prevent the concrete from gaining its full strength, but it will also generate internal stresses that can cause cracking. To keep fresh and young concrete moist, it can be covered with plastic or damp fabric to prevent evaporation, or sprayed periodically with water. Spraying is particularly helpful when the w/c of the concrete is low, because the original mix water is not enough for the cement to hydrate fully. The additional water will not penetrate through a thick concrete structure, but it will help create a stronger surface layer. Pools of water should not be allowed to form on the surface, however, as this will leach and degrade the concrete underneath.

When concrete is placed using formwork, there is generally a desire to remove the formwork as quickly as possible to continue the construction process. However, if this is done too soon the fresh concrete will deform under its own weight. This will lead to a loss of dimensional tolerances, cracking, or even a complete collapse. Similar problems occur if loads are applied to the surface of a floor or slab too early.

The weather plays an important role in the curing process. Hot windy weather leads to rapid evaporation and thus particular care must be taken to keep the concrete moist. Cold weather causes the concrete to harden much more slowly than hot weather. This delays the construction process, but leads to better concrete in the long run, because the hydration products develop differently at different temperatures. If fresh concrete freezes, however, it will likely be destroyed beyond repair.





## 8. FINISHING

Concrete that will be visible, such as driveways, highways, or patios, often needs finishing. Slabs can be finished in many ways, depending on the intended service use. Options include various colors and textures, such as exposed aggregate or a patterned-stamped surface. Some surfaces may require only strike off and screeding to proper contour and elevation, while for other surfaces a broomed, floated, or troweled finish may be specified.

Screeding or strike off is the process of cutting off excess concrete to bring the top surface of the slab to proper grade. A straight edge is moved across the concrete with a sawing motion and advanced forward a short distance with each movement.

Bull floating eliminates high and low spots and embeds large aggregate particles immediately after strike off. This looks like a long-handled straight edge pulled across the concrete.

Jointing is required to eliminate unsightly random cracks. Contraction joints are made with a hand groover or by inserting strips of plastic, wood, metal, or preformed joint material into the unhardened concrete. Saw cut joints can be made after the concrete is sufficiently hard or strong enough to prevent raveling.

After the jointing the concrete, it should be floated with a wood or metal hand float or with a finishing machine using float blades. This embeds aggregate particles just beneath the surface; removes slight imperfections, humps, and voids; and compacts the mortar at the surface in preparation for additional finishing operations.

Where a smooth, hard, dense surface is desired, floating should be followed by steel troweling. Troweling should not be done on a surface that has not been floated; troweling after only bull floating is not an adequate finish procedure. A slip-resistant surface can be produced by brooming before the concrete has thoroughly hardened, but it should be sufficiently hard to retain the scoring impression.



***Troweling***



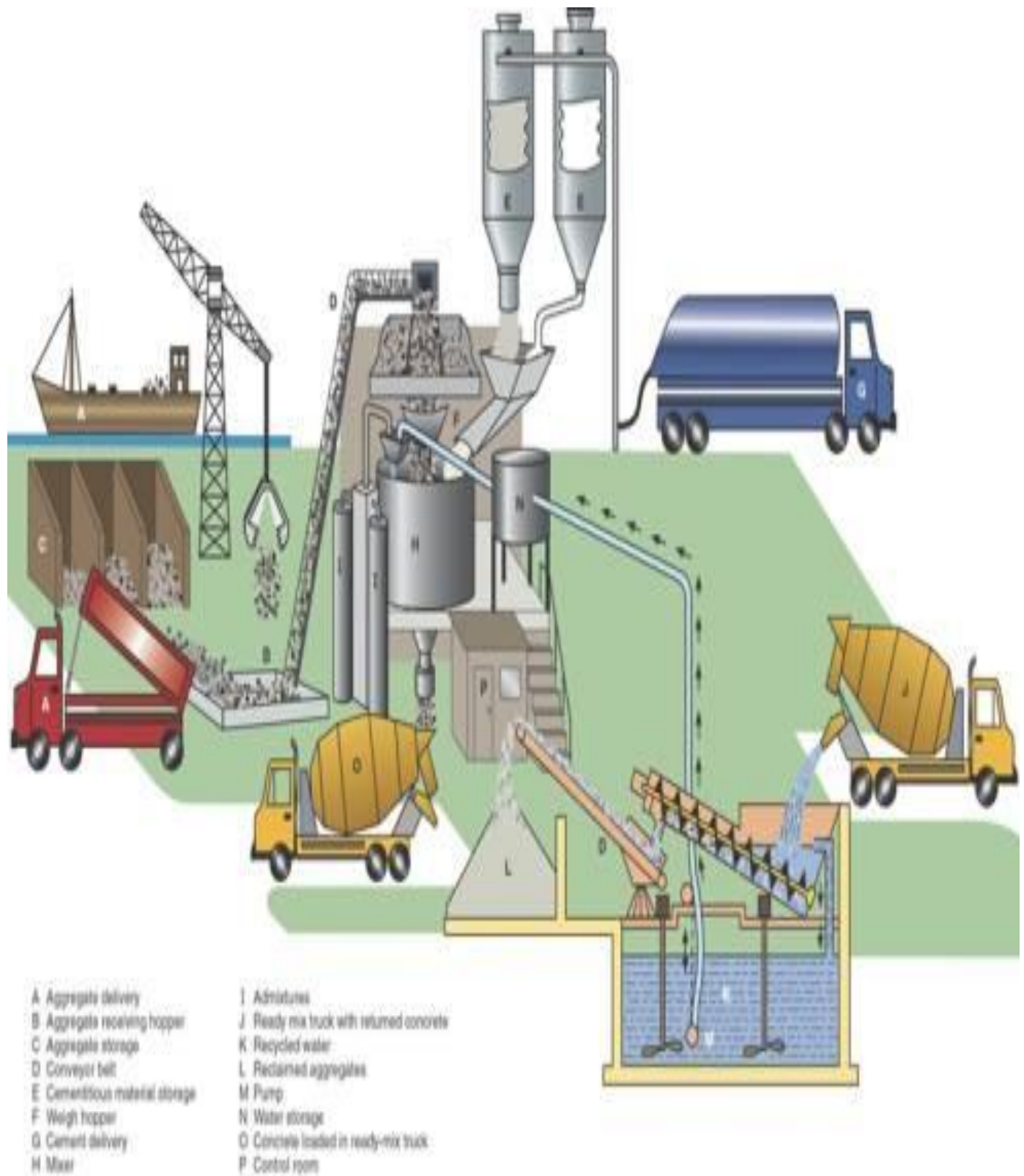
***Groover (Grooving for joints)***



***Brooming***



***Screeding***



*Overall manufacturing process*



## **READY MIX CONCRETE**

Ready mixed concrete production is a process, whereby, mixing and transportation of concrete can be combined together and the product is delivered to the site, at times right in the mould straight away. According to IS-4926, the definition of Ready mixed concrete is: “Concrete delivered at site or in to the purchaser’s vehicle in a plastic condition and requiring no further treatment before being placed in position in which it is to set and harden”.

### *Factors Delaying Entry of RMC in India*

- RMC is highly mechanized activity and entails initial high cost.
- Especially due to import of basic equipment and machinery.
- Smaller size of construction in unorganized sector highly competitive and cost conscious.
- Availability of abundant cheap labor for making and transporting concrete.
- Differential taxation between RMC and SMC.
- Especially before 1997 when excise duty @16% also existed.

### *Factors that Prompted Introduction of RMC*

- Increasing stakes in the reliability and durability of construction of emerging users.
- Decreasing share of construction cost in overall cost of the facility.
- Increasing awareness on environmental factors and convenience.
- Globalization – adoption of best practices across the globe.
- Bigger size of projects and Time is recognized as a cost factor.

### *Status of RMC in India*

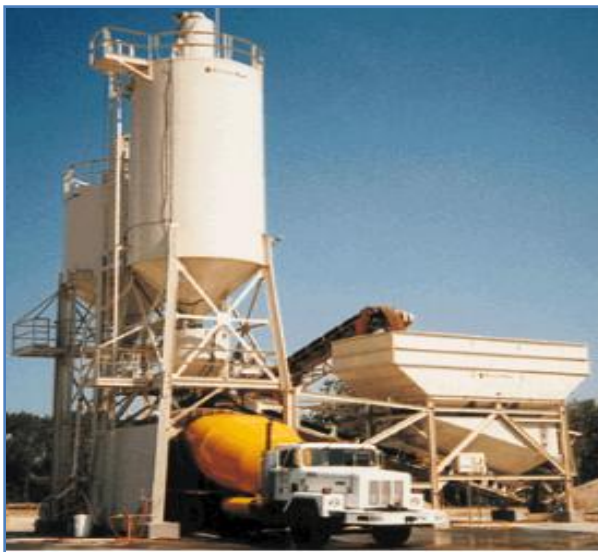
Geographical Distribution	No. of Plants	
	2001 – 2002	2004 – 2005
Bangalore – Mysore Belt	12	35
Chennai – Trichannapali	8	25
Hyderabad – Vizag	6	12
Pune	2	10
Mumbai, Navi Mumbai	12	25
Goa	1	2
Delhi, Gurgaon, Faridabad, Noida	5	25
Kolkatta	1	3
Ahemdabad, Surat	-	3
Jaipur	-	2
Sundry	-	5
<b>Total</b>	<b>47</b>	<b>147</b>

*Expected growth of commercial RMC in India*

Year	Total Concrete consumption (Million m <sup>3</sup> )	Concrete in domain of RMC plants at 80% of 2	RMC penetration % of 2	Total RMC requirement (Mnm <sup>3</sup> )	RMC penetration in domain of commercial RMC (5 ÷ 3) (%)
(1)	(2)	(3)	(4)	(5)	(6)
2002	182	145.6	1.3	2.4	1.6
2005	243	194.4	4.35	10.58	5.6
2007	314	251.2	5.75	17.8	7.08
2012	440	352.0	7.25	31.90	9.06
2017	589	471.2	8.75	51.53	10.72
2022	788	630.4	10.00	78.80	12.50

*Dry Batch Concrete Plant Major Components*

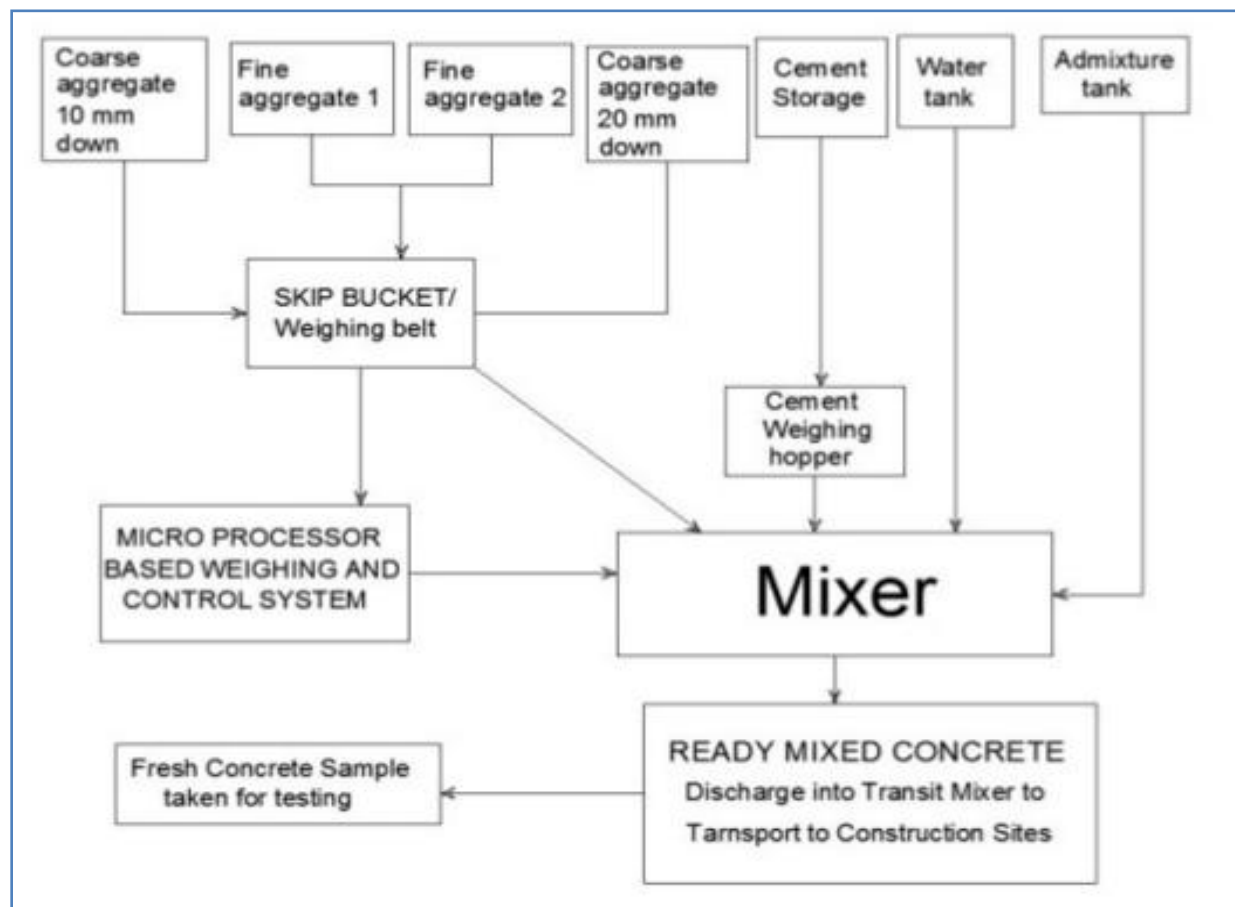
- Bulk Dry Storage Silos o Cement o Fly Ash
- Aggregate Storage Bins
- Aggregate Scale
- Cementitious Scale
- Charging Belt
- Radial Stacker
- Water Meter / Scale
- Discharge Boot



*A typical RMC*



### Flowchart for Manufacturing of concrete in RMC



### ❖ Raw Material used to produce Concrete

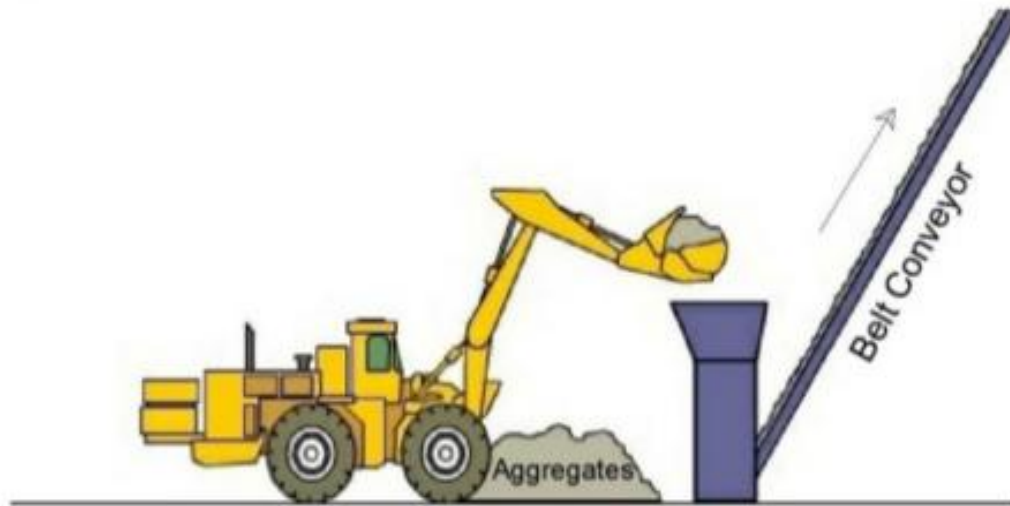


- Ready-mix concrete is made from cement, aggregate and water.
- Aggregate make up majority of the concrete's volume and the cement provides resistance.
- Additives are incorporated into the mix to ensure particular properties such as improved durability or shortened hardening times.
- During the mixing phase, we control every step to ensure quality and uniformity.

#### **Raw Materials are:-**

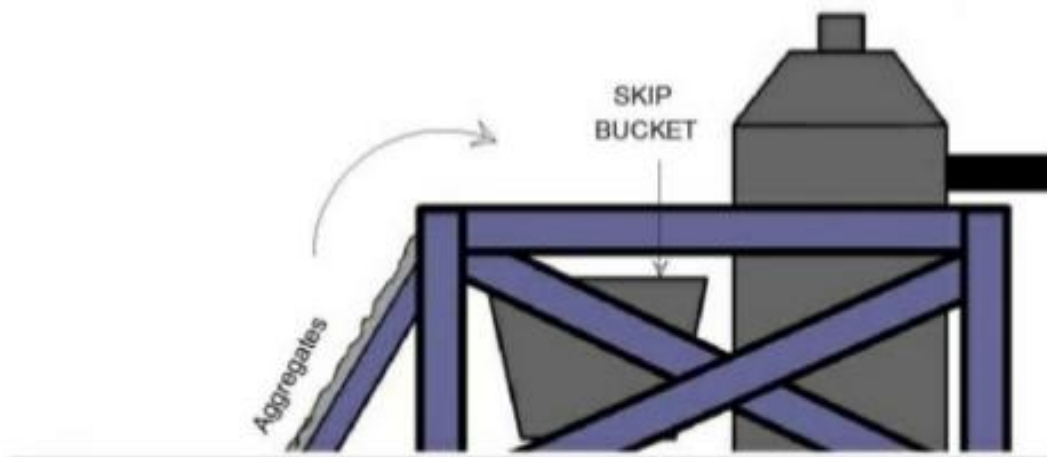
1. Water
2. Additives
3. Cement
4. Aggregate
5. Air

### ❖ Aggregates



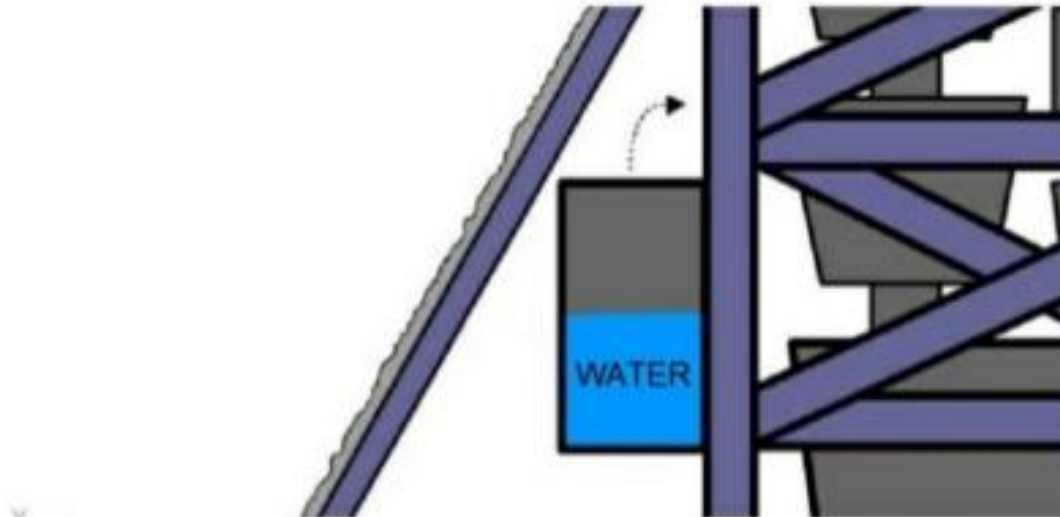
- Aggregates, which make up roughly 60% to 75% of ready mix concrete's volume, are obtained from quarries and aggregate banks.

### ❖ Additives



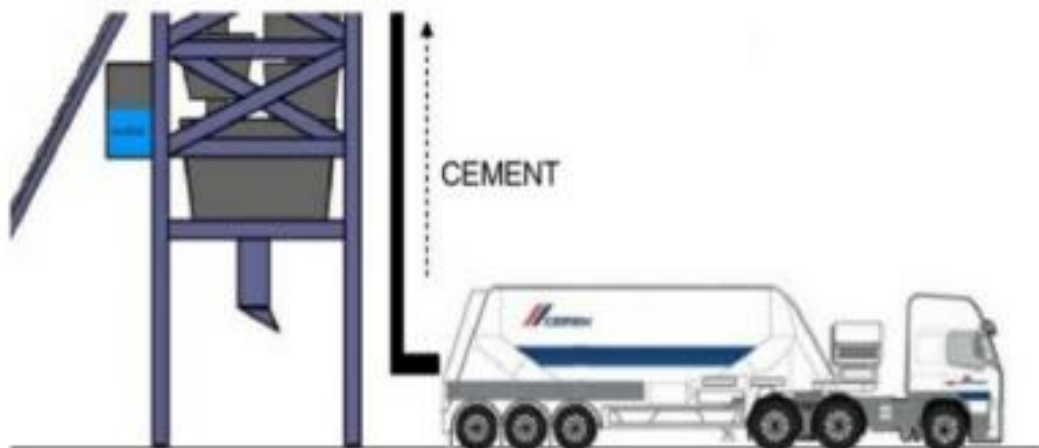
- Additives are solid or liquid chemical substance that can be added to ready mix concrete before or during preparation.
- Most commonly used additives either improve a hardened concrete's durability or reduce a concrete's water content in an effort to shorten setting times.

❖ Water



- This is the mix's vital fluid sets off a chemical reaction when it comes into contact with the cement.

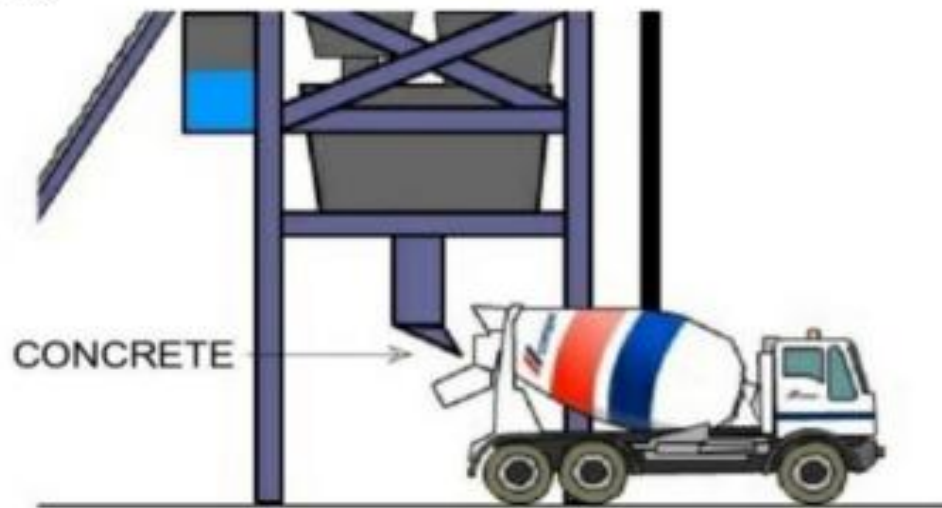
❖ Cement



- No other material rivals cement's importance in the mix; it's the ingredient that gives concrete its strength.
- The most widely used cements are gray Portland type 1 and Pozzolona Portland type 2.



❖ **Concrete mixing**



- During the mixing phase, the different components come together to produce a uniform mass of concrete.
- Mixing time is registered from the movement material and water is poured into the cement mixer, and it begins rotating.

❖ **Ready to use for site**



- While transporting concrete to a site, the cement mixer never stops revolving at a speed of two to six rotations per minute.

### ***RMC- MAJOR ADVANTAGES***

- Assured and Uniform Quality of Concrete
- Speedier Construction through mechanized operations
- Need For Ordering and Storing Cement, Aggregates and Sand on Site Totally Eliminated
- Lower Labor And Supervisory Costs
- Minimization of cement wastage through bulk handling and storage
- Cleaner working environment
- Eco-friendly product

### ***RMC DISADVANTAGES***

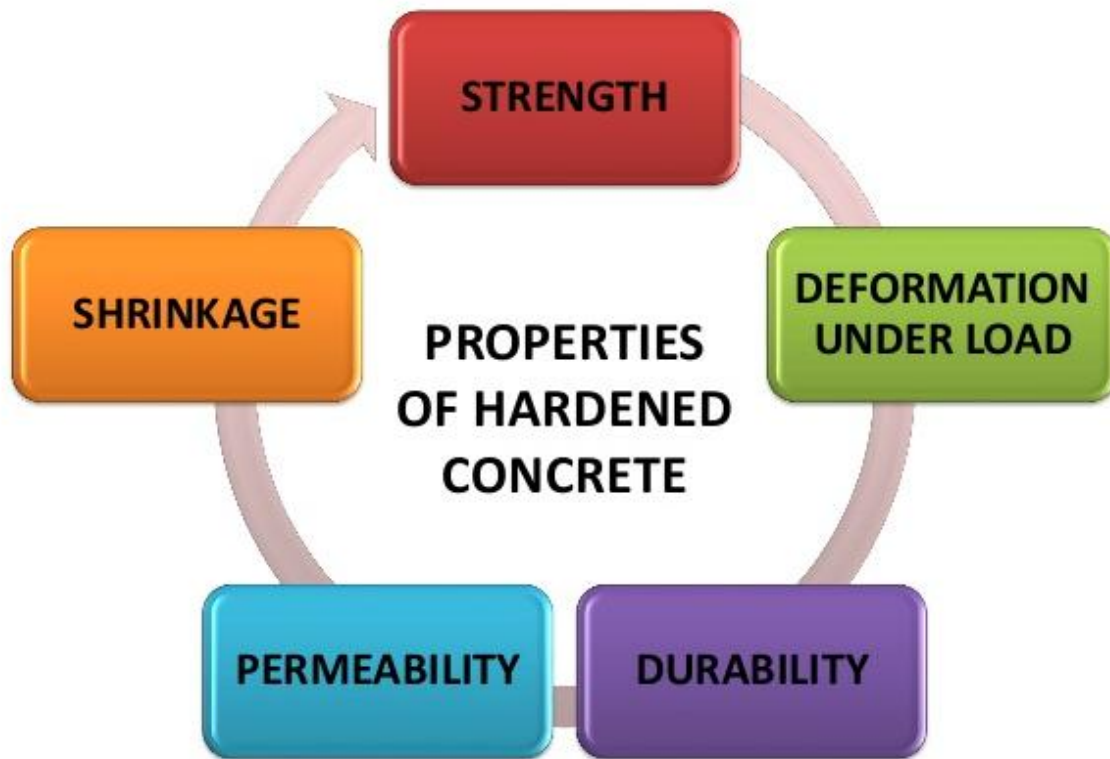
- Delay in setting of concrete beyond 24 hours.
- Development of cracks when the concrete is still in fresh state.
- Development of cracks in hardened concrete.
- Non-compliance of concrete cube strength (cast at site) to specifications at 7-days.
- Non-compliance of concrete cube strength (cast at site) to specifications at 28-days.
- Concrete supplied to site either has more slump than specified or has become stiff making it difficult to pump.

### **PROPERTIES OF HARDENED CONCRETE**

Characteristic strength, drying shrinkage, creep, modulus of elasticity, permeability and resistance to chemical attack are hardened and time-dependent properties of concrete that may influence structural performance.

Structural performance may be described in terms of:

- Strength: The ability of the structure to withstand load.
- Serviceability: The ability of the structure to provide a comfortable, aesthetic environment when used for intended functions.
- Durability: The time for which the structure is serviceable, and the maintenance required for it to remain serviceable. The ability of a structure to withstand load does not necessarily imply that the structure will fulfill its function.



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### **STRENGTH OF CONCRETE**

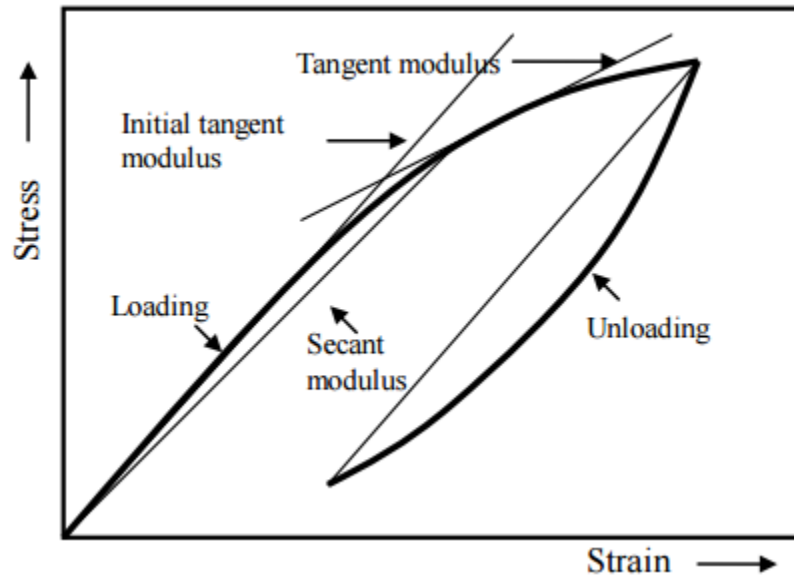
In concrete design and quality control, strength is the property generally specified. This is because, compared to most other properties, testing strength is relatively easy. Furthermore, other properties of concrete, such as elastic modulus, water tightness or impermeability, and resistance to weathering agents including aggressive waters, are directly related to strength and can therefore be deduced from the strength data.

To determine the strength of concrete three types of tests are followed;

1. Compressive strength test
2. Tensile strength test
3. Flexural strength test

**ELASTICITY** - The modulus of elasticity, denoted as  $E$ , is defined as the ratio between normal stress to strain below the proportional limit of a material and it is used to measure instantaneous elastic deformation. Since no test exist to evaluate the direct elastic modulus of concrete, the

proportional limit is evaluated by means of a value which is used to establish the limit used for the curves in the repeated applications of load. The elastic modulus is then calculated by determining the slope of the straight line in the stress-strain diagram.



Since the stress-strain curve for concrete is nonlinear, following methods for computing the modulus of elasticity of concrete are used yielding various types of modulus of elasticity for concrete:

The “*initial tangent modulus*” It is given by the slope of a line drawn tangent to the stress-strain curve at the origin

The “*tangent modulus*” It is given by the slope of a line drawn tangent to the stress-strain curve at any point on the curve

The “*secant modulus*” It is given by the slope of a line drawn from the origin to a point on the curve corresponding to a 40% stress of the failure stress

The “*chord modulus*” It is given by the slope of a line drawn between two points on the stress-strain curve

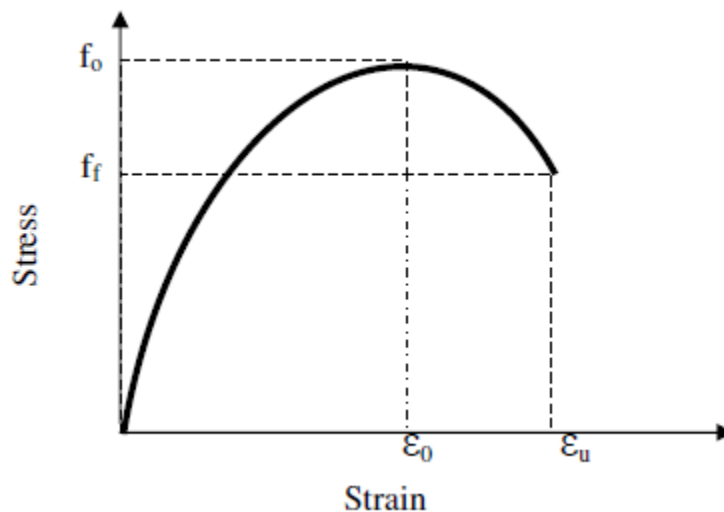
### Typical Stress-Strain Plot of Concrete

- At stress below 30% of ultimate strength, the transition zone cracks remain stable. The stress-strain plot remains linear.



- At stress between 30% and 50% of ultimate strength, the transition zone micro cracks begin to increase in length, width and numbers. The stress-strain plot becomes non-linear.
- At 50 to 60% of the ultimate stress, cracks begin to form in the matrix. With further increase to about 75% of the ultimate stress, the cracks in the transition become unstable, and crack propagation in the matrix will increase. The stress-strain curve bends towards the horizontal.
- At 75 to 80% of the ultimate stress, the stress reaches a critical stress level for spontaneous crack growth under a sustained stress. Cracks propagate rapidly in both the matrix and the transition zone. Failure occurs when the cracks join together and become continuous.

Concrete is *not a truly elastic material*, as evident from the *nonlinear stress-strain curve* for concrete



**SHRINKAGE** - Shrinkage of concrete is the time-dependent strain measured in an unloaded and unrestrained specimen at constant temperature

To understand this aspect more closely, shrinkage can be classified in the following ways;

1. Plastic Shrinkage
2. Drying Shrinkage
3. Autogeneous Shrinkage
4. Carbonation Shrinkage

***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. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement. 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 of concrete collapses causing the 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 reverberate the concrete in a controlled manner. Use of small quantity of aluminum powder 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. The principal property of such cement is that the expansion induced in the plastic concrete will almost offset the normal shrinkage due to loss of moisture. Under correct usage, the distance between the joints can sometimes be tripled without increasing the level of shrinkage cracking. Further, use of unneeded high slump concrete, over sanded mix, higher air entraining should be discouraged in order to reduce the higher plastic shrinkage.

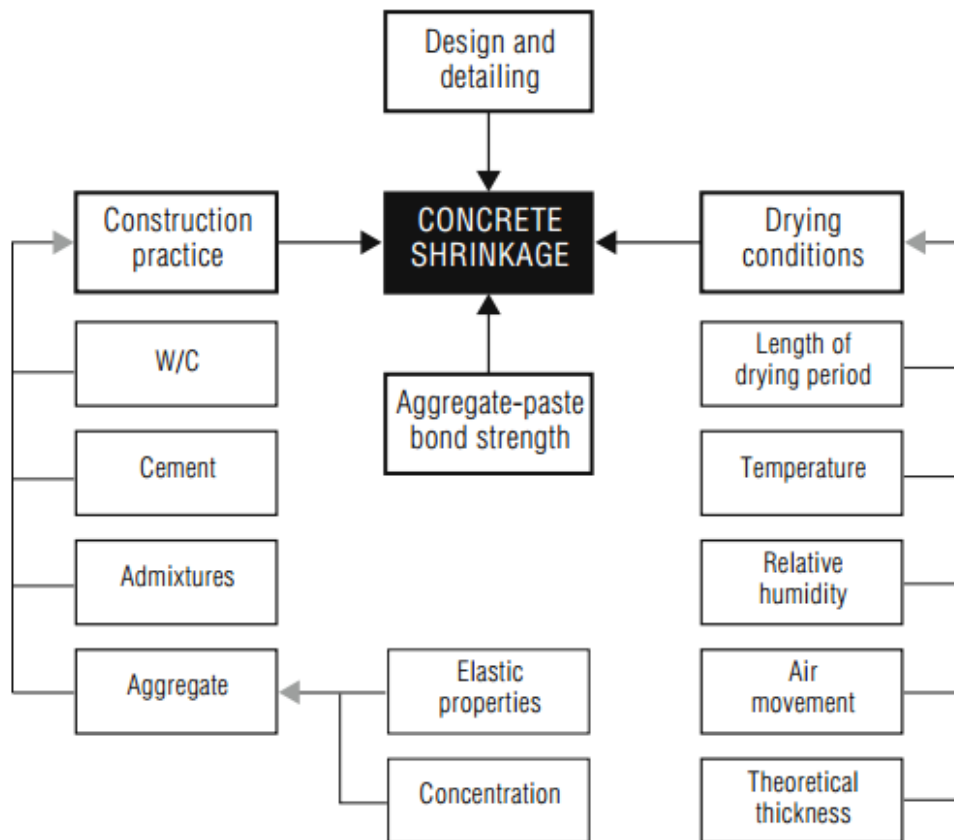


### ***Plastic shrinkage***

***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 microns. But values up to 4,000 microns have 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.



*Drying Shrinkage*



*Factors affecting dry shrinkage*



***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 microns.

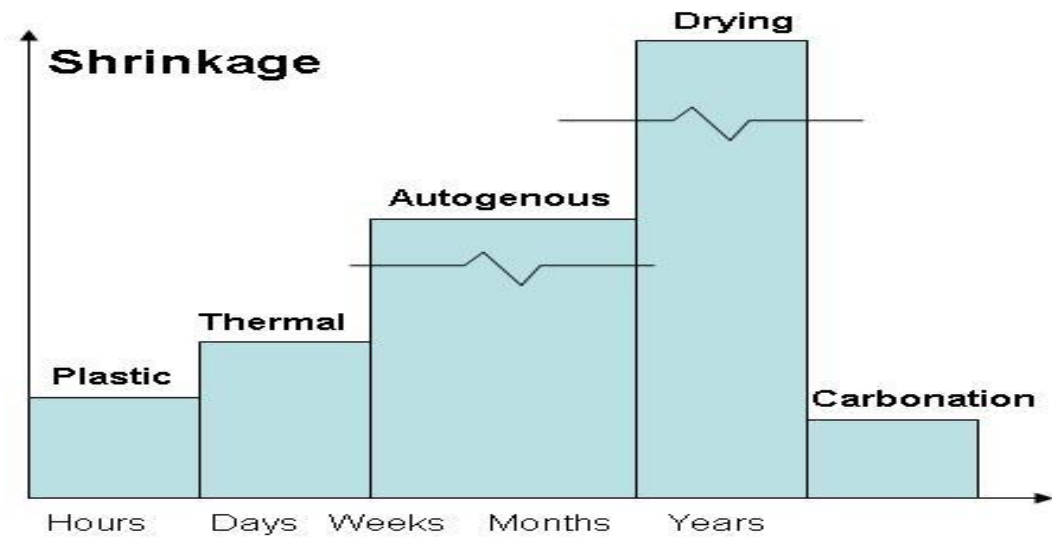


***Carbonation Shrinkage*** - Carbonation shrinkage is a phenomenon very recently recognised. Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide gets converted to calcium carbonate and also some other cement compounds are decomposed. Such 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 up to steel reinforcements, the steel becomes liable for corrosion. 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





***CREEP*** - Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.





## **Factors Affecting Creep**

1. Aggregate
2. Mix Proportions
3. Age of concrete

**1. Influence of Aggregate** - Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of 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. Light weight aggregate shows substantially higher creep than normal weight aggregate.

**2. Influence of Mix Proportions** - 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 water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

**3. Influence of Age** - Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

## **Effects of Creep on Concrete and Reinforced Concrete**

- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can lead 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.

### **DURABILITY OF CONCRETE**

The ability of concrete to withstand the conditions for which it is designed without deterioration for a long period of years is known as durability. In other words it can also be expressed as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete.

*Concrete will remain durable if:*

- The cement paste structure is dense and of low permeability
- Under extreme condition, it has entrained air to resist freeze-thaw cycle.
- It is made with graded aggregate that are strong and inert
- The ingredients in the mix contain minimum impurities such as alkalis, Chlorides, Sulphates and silt

### **Factors affecting durability of concrete**

**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, water / cement ratio increases and resulting in highly permeable material.

**Compaction** - The concrete as a whole contain voids can be caused by inadequate compaction. Usually it is being governed by the compaction equipments used, type of formworks, and density of the steelwork

**Curing** - It is very important to permit proper strength development aid moisture retention and to ensure hydration process occur completely

**Cover** - Thickness of concrete cover must follow the limits set in codes

**Permeability** - It is considered the most important factor for durability. It can be noticed that higher permeability is usually caused by higher porosity .Therefore, a proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete

There are many types but the major Concrete Durability types are:

1. **Physical durability**
2. **Chemical durability**

### **1. Physical Durability**

Physical durability is against the following actions

1. Freezing and thawing action
2. Percolation / Permeability of water
3. Temperature stresses i.e. high heat of hydration

### **2. Chemical Durability**

Chemical durability is against the following actions

1. Alkali Aggregate Reaction
2. Sulphate Attack
3. Chloride Ingress
4. Delay Ettringite Formation
5. Corrosion of reinforcement

## **Causes for the Lack of Durability in Concrete**

### **1. External Causes:**

- a. Extreme Weathering Conditions
- b. Extreme Temperature
- c. Extreme Humidity
- d. Abrasion
- e. Electrolytic Action
- f. Attack by a natural or industrial liquids or gases

### **2. Internal Causes**

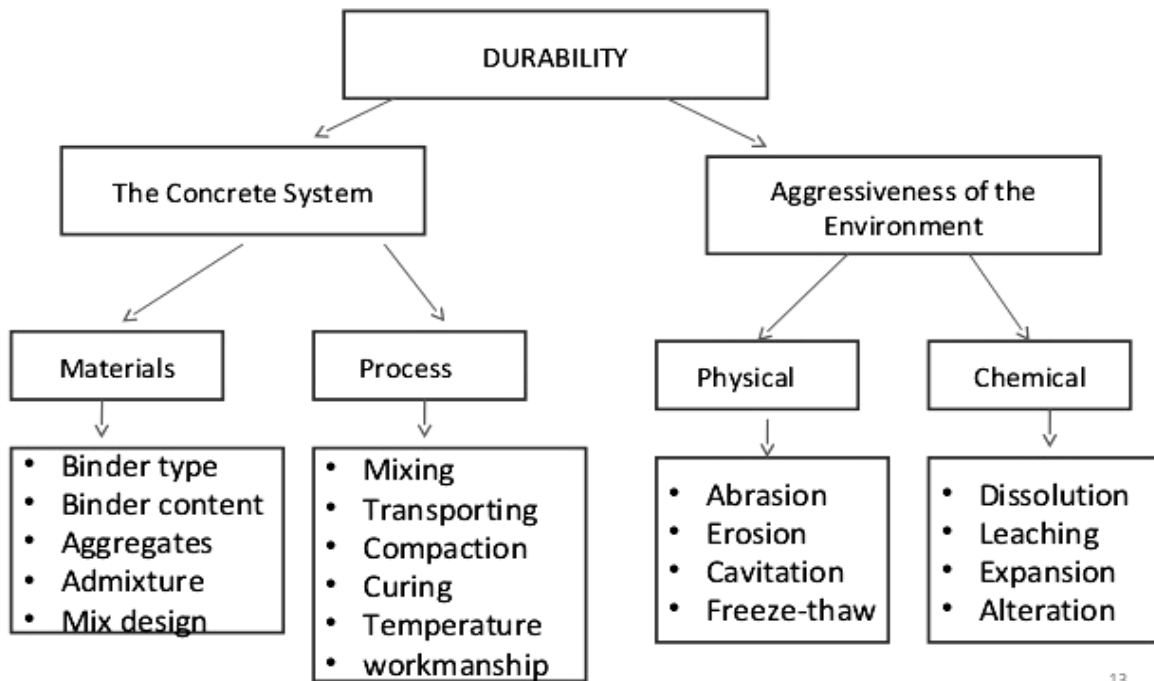
#### **a) Physical**

- Volume change due to difference in thermal properties of aggregates and cement paste
- Frost Action

#### **b) Chemical**

- Alkali Aggregate Reactions
  - ❖ Alkali Silica Reaction
  - ❖ Alkali Silicate Reaction
  - ❖ Alkali Carbonate Reaction
- Corrosion of Steel

# Factors Affecting Durability



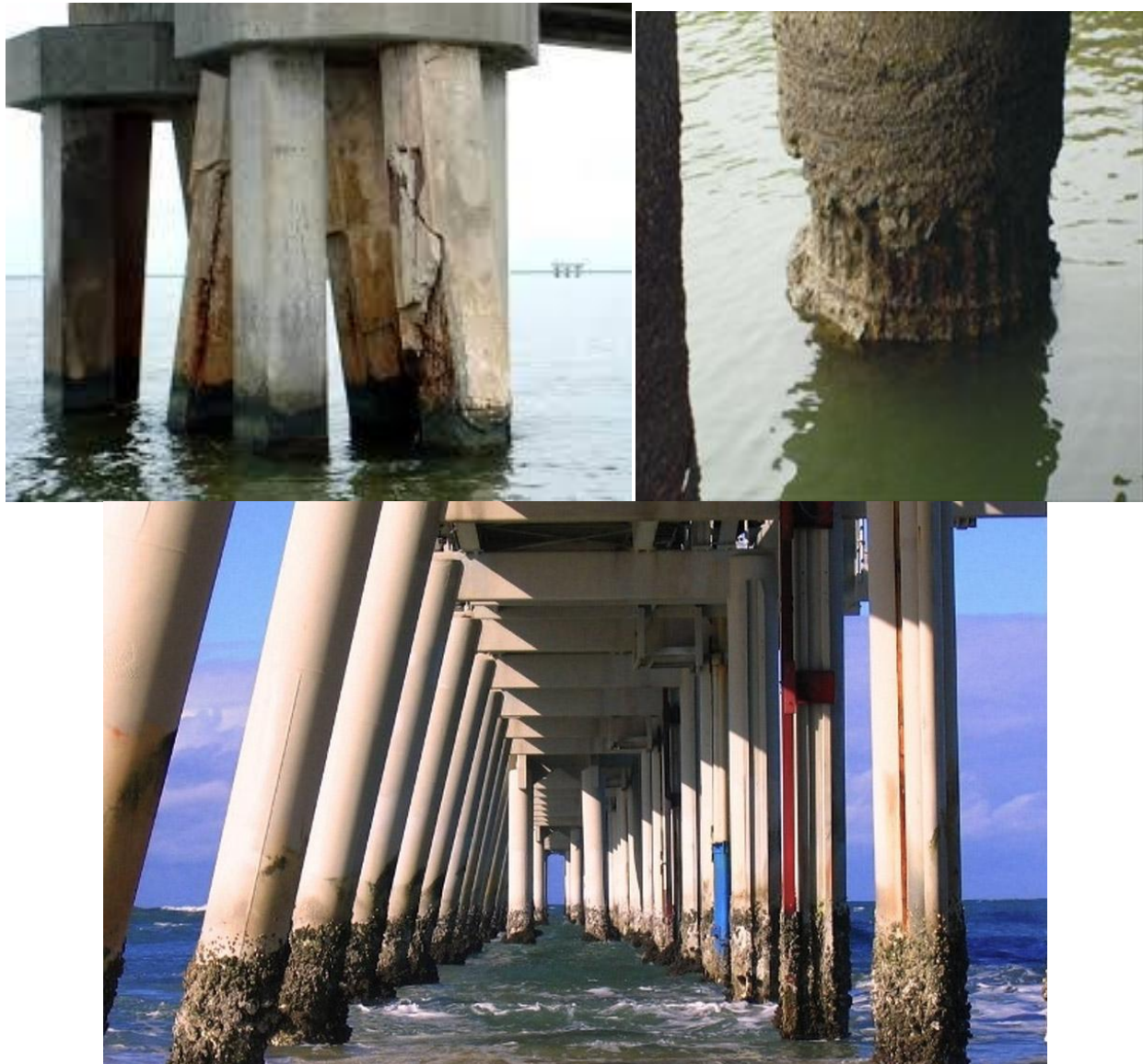
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Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete.

***Seawater Exposure*** - Concrete has been used in seawater exposures for decades with excellent performance. However, special care in mix design and material selection is necessary for these severe environments. A structure exposed to seawater or seawater spray is most vulnerable in the tidal or splash zone where there are repeated cycles of wetting and drying and/or freezing and thawing. Sulfates and chlorides in seawater require the use of low permeability concrete to minimize steel corrosion and sulfate attack. A cement resistant to sulfate exposure is helpful. Proper concrete cover over reinforcing steel must be provided, and the water-cementitious ratio should not exceed 0.40.



***Chloride Resistance and Steel Corrosion*** - Chloride present in plain concrete that does not contain steel is generally not a durability concern. Concrete protects embedded steel from corrosion through its highly alkaline nature. The high pH environment in concrete (usually greater than 12.5) causes a passive and non corroding protective oxide film to form on steel. However, the presence of chloride ions from deicers or seawater can destroy or penetrate the film. Once the chloride corrosion threshold is reached, an electric cell is formed along the steel or between steel bars and the electrochemical process of corrosion begins.

The resistance of concrete to chloride is good; however, for severe environments such as bridge decks, it can be increased by using a low water-cementitious ratio (about 0.40), at least seven days of moist curing, and supplementary cementitious materials such as silica fume, to reduce permeability. Increasing the concrete cover over the steel also helps slow down the migration of chlorides. Other methods of reducing steel corrosion include the use of corrosion inhibiting admixtures, epoxy-coated reinforcing steel, surface treatments, concrete overlays, and cathodic protection.



***Resistance to Alkali-Silica Reaction (ASR)*** - ASR is an expansive reaction between reactive forms of silica in aggregates and potassium and sodium alkalis, mostly from cement, but also from aggregates, pozzolans, admixtures, and mixing water. The reactivity is potentially harmful only when it produces significant expansion. Indications of the presence of alkali-aggregate reactivity may be a network of cracks, closed or spalling joints, or movement of portions of a



structure. ASR can be controlled through proper aggregate selection and/or the use of supplementary cementitious materials (such as fly ash or slag cement) or blended cements proven by testing to control the reaction.



***Abrasion Resistance*** - Concrete is resistant to the abrasive affects of ordinary weather. Examples of severe abrasion and erosion are particles in rapidly moving water, floating ice, or areas where steel studs are allowed on tires. Abrasion resistance is directly related to the strength of the concrete. For areas with severe abrasion, studies show that concrete with compressive strengths of 12,000 to 19,000 psi work well.



### **Concrete Crack**

Concrete, like most materials, will shrink slightly when it dries out. Common shrinkage is about 1/16th of an inch in a 10-foot length of concrete. The reason contractors place joints in concrete pavements and floors is to allow the concrete to crack in a neat, straight line at the joint, where concrete cracks due to shrinkage are expected to occur. Control or construction joints are also placed in concrete walls and other structures.



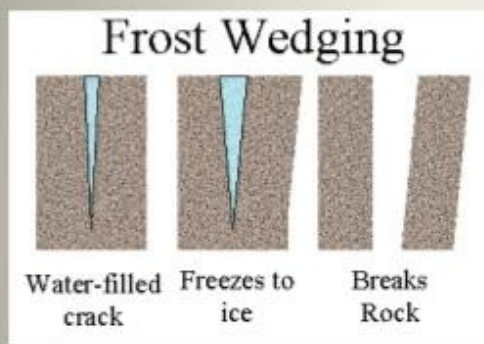
### ***Moderate to Severe Exposure Conditions for Concrete***

The following are important exposure conditions and deterioration mechanisms in concrete. Concrete can withstand these effects when properly designed. The Specifier's Guide for Durable Concrete is intended to provide sufficient information to allow the practitioner to select materials and mix design parameters to achieve durable concrete in a variety of environments.

***Resistance to Freezing and Thawing*** - The most potentially destructive weathering factor is freezing and thawing while the concrete is wet, particularly in the presence of deicing chemicals. Deterioration is caused by the freezing of water and subsequent expansion in the paste, the aggregate particles, or both. With the addition of an air entrainment admixture, concrete is highly resistant to freezing and thawing. During freezing, the water displaced by ice formation in the paste is accommodated so that it is not disruptive; the microscopic air bubbles in the paste provide chambers for the water to enter and thus relieve the hydraulic pressure generated.

Concrete with a low water-cementitious ratio (0.40 or lower) is more durable than concrete with a high water-cementitious ratio (0.50 or higher). Air-entrained concrete with a low water-cementitious ratio and an air content of 5 to 8% will withstand a great number of cycles of freezing and thawing without distress.

## Freezing and Thawing



### Effect of Admixtures on concrete

As can be predicted from the effect of water-cement ratio on shrinkage, admixtures that increase the water requirement of concrete increase shrinkage and those that decrease the water requirement decrease it. Calcium chloride in the amount often added as an accelerator – 2 per cent by weight of the amount of cement – may increase drying shrinkage by as much as 50 per cent.



The over-all effect of the use of air entrained concrete is not to increase shrinkage. Some admixtures, if used in somewhat larger than normal doses, do increase shrinkage greatly and care must be exercised in the proportioning

***CHEMICAL ATTACKS CARBONATION*** - Chemical attacks on concrete structures causes deterioration of structure and its durability is affected. The life of structure reduces and it can lead to failure of structures. The various types of chemical attacks and their effects on concrete structures are discussed below:

**(a) Chlorides attacks on concrete structures:**

High concentrations of chloride ions cause corrosion of reinforcement and the products of corrosion can disrupt the concrete. Chlorides can be introduced in to the concrete either during or after construction as follows.

- (i) Before construction Chlorides can be admitted in admixtures containing calcium chloride, through using mixing water contaminated with salt water or improperly washed marine aggregates.
- (ii) After construction Chlorides in salt or sea water, in airborne sea spray and from de-icing salts can attack permeable concrete causing corrosion of reinforcement.



***Chemical attack on concrete columns***

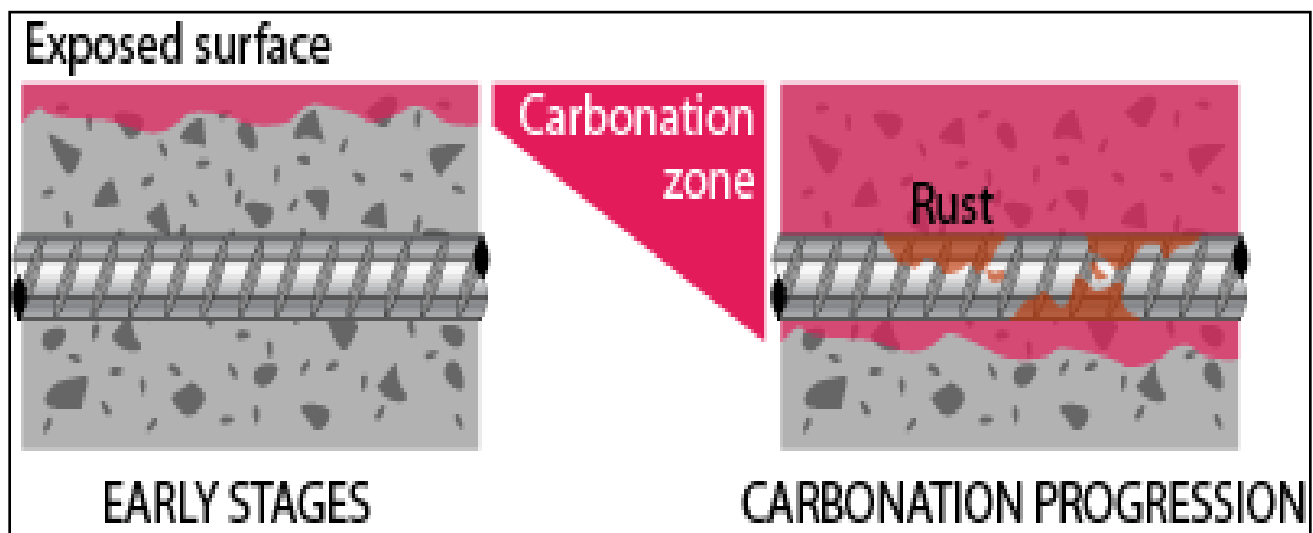
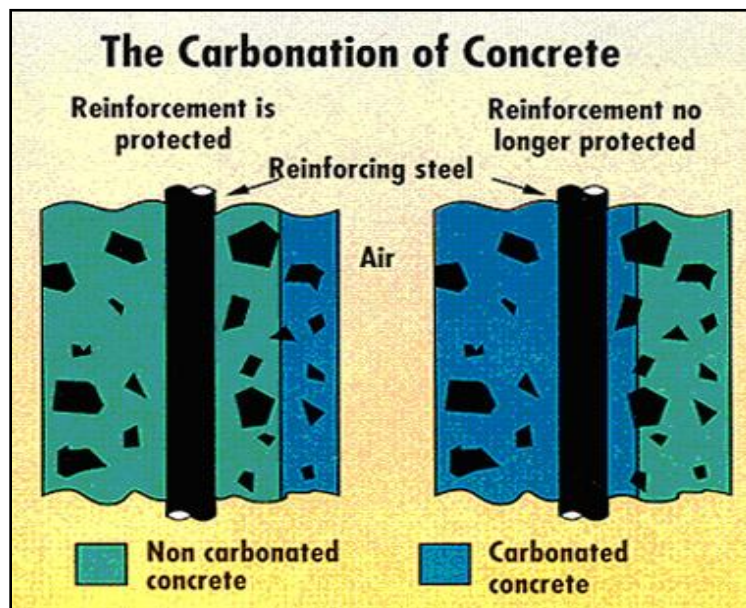
**(b) Sulphates attacks on concrete structures:**

Sulphates are present in most cement and some aggregates. Sulphates may also be present in soils, groundwater and sea water, industrial wastes and acid rain. The products of sulphate attack on concrete occupy a larger space than the original material and this causes the concrete to disintegrate and permits corrosion of steel to begin. BS8110: Part 1, clause 6.2.5.3, states that the total water-soluble sulphate content of the concrete mix expressed as  $\text{SO}_3$  should not exceed 4% by mass of cement in the mix. Sulphate-resisting Portland cement should be used where sulphates are present in the soil, water or atmosphere and come into contact with the concrete. Super-sulphated cement, made from blast furnace slag can also be used although it is not widely available. This cement can resist the highest concentrations of sulphates.

**(c) Carbonation of concrete structures:**

Carbonation is the process by which carbon dioxide from the atmosphere slowly transforms calcium hydroxide into calcium carbonate in concrete. The concrete itself is not harmed and increases in strength, but the reinforcement can be seriously affected by corrosion as a result of this process.

Normally the high pH value of the concrete prevents corrosion of the reinforcing bars by keeping them in a highly alkaline environment due to the release of calcium hydroxide by the cement during its hydration. Carbonated concrete has a pH value of 8.3 while the passivation of steel starts at a pH value of 9.5. The depth of Carbonation in good dense concrete is about 3 mm at an early stage and may increase to 6–10 mm after 30–40 years. Poor concrete may have a depth of Carbonation of 50 mm after say 6–8 years. The rate of Carbonation depends on time, cover, concrete density, cement content, water-to-cement ratio and the presence of cracks.





## Measurement of Depth of Carbonation



Pink color indicates that  $\text{Ca}(\text{OH})_2$  is unaffected by carbonation  
The uncolored portion indicates that concrete is carbonated

### (d) Alkali—silica reaction in concrete structures:

A chemical reaction can take place between alkali in cement and certain forms of silica in aggregate. The reaction produces a gel which absorbs water and expands in volume, resulting in cracking and disintegration of the concrete.

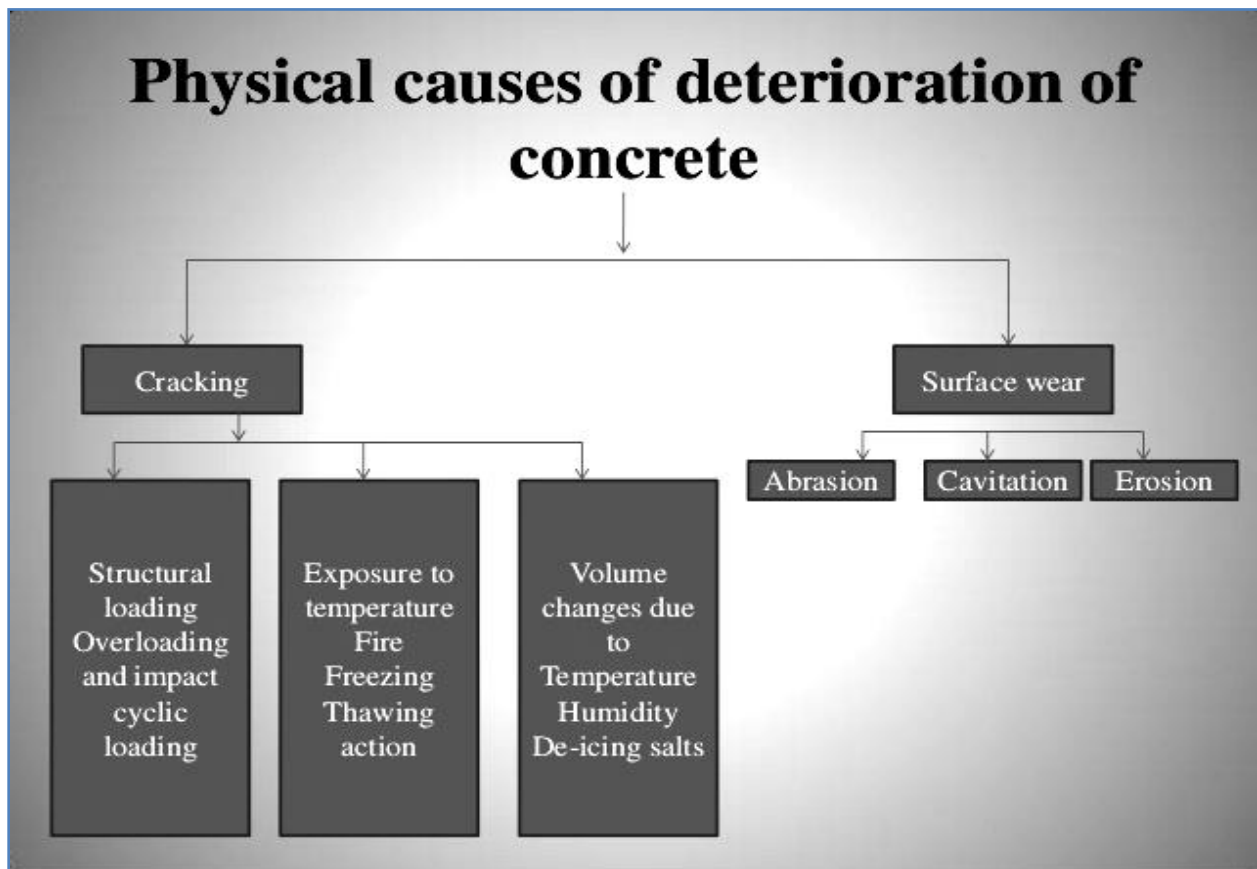
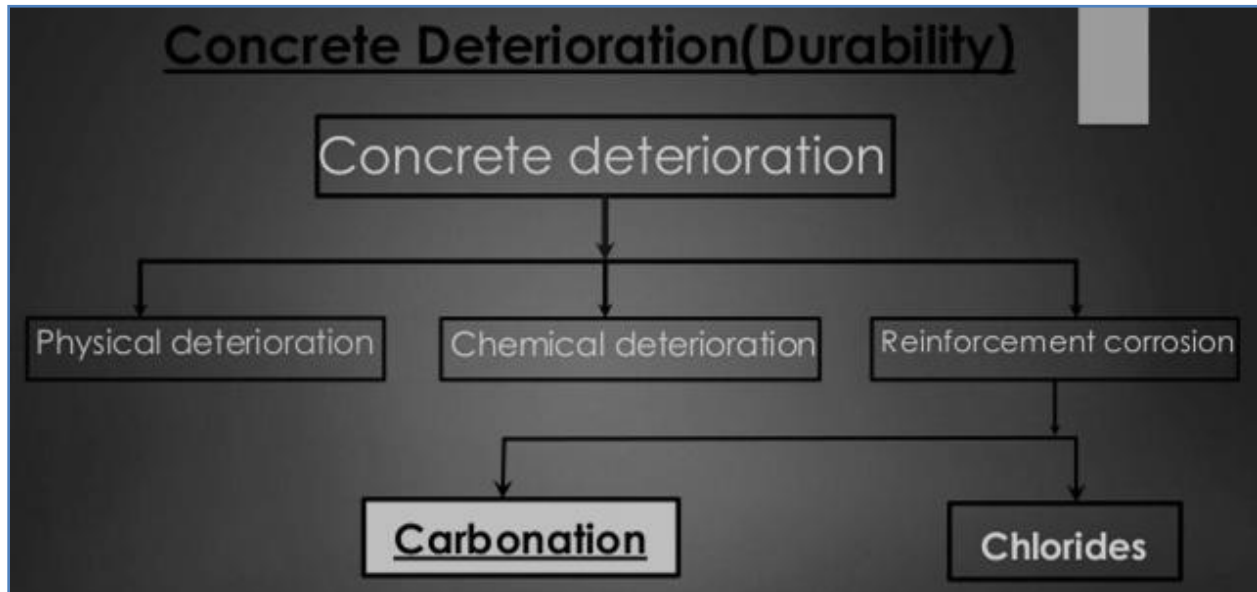
The reaction only occurs when the following are present together:

1. a high moisture level in the concrete
2. cement with a high alkali content or some other source of alkali
3. aggregate containing an alkali-reactive constituent

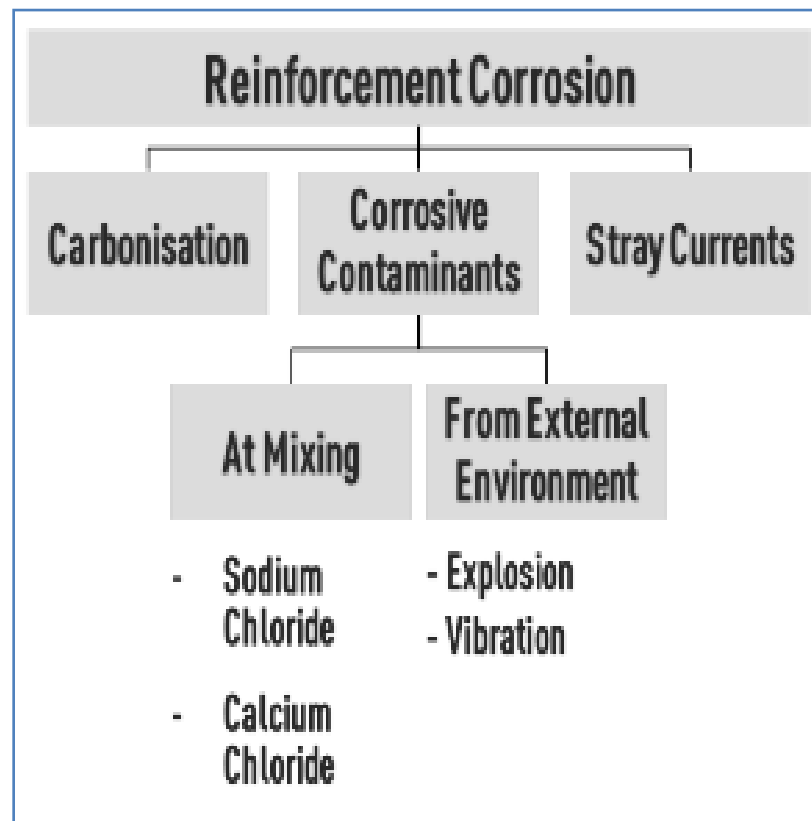
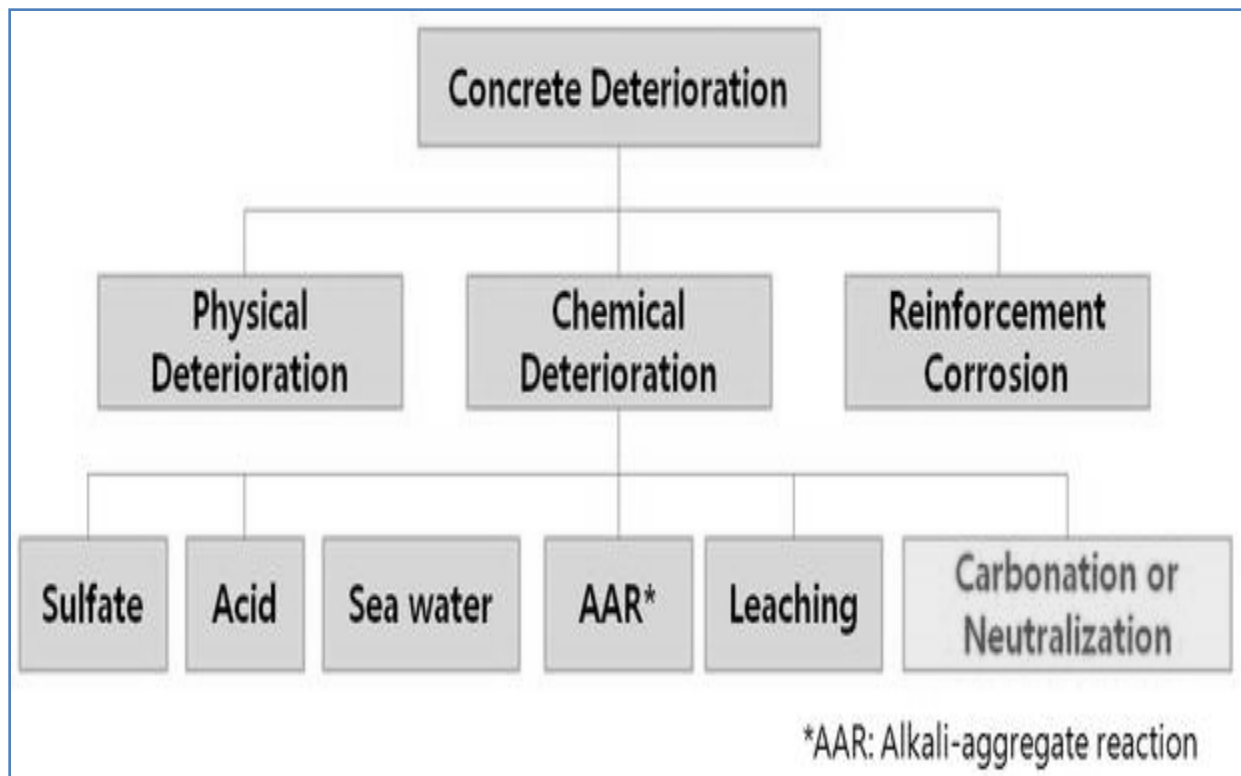
The code recommends that the following precautions be taken if uncertainty exists:

1. Reduce the saturation of the concrete;
2. Use low alkali Portland cement and limit the alkali content of the mix to a low level;
3. Use replacement cementitious materials such as blast furnace slag or pulverized fuel ash. Most normal aggregates behave satisfactorily.

## DETERIORATION OF CONCRETE







## **DURABILITY OF CONCRETE IN MARINE ENVIRONMENT**

Concrete has had extensive use as construction material for seaways, jetties, groins, breakwaters, bulk-heads and other structures exposed to sea water. The performance record has generally been good but there are some causes occurring on the structures due to few conditions. Freezing and thawing cycles is one cause of marine concrete deterioration i.e., due to the expansion of ice crystals concrete will be under such conditions which tend to crumble and spall. Other causes are chemical in nature and relate to the corrosion of reinforcing steel, sulfate water attack on the concrete or aggregate reaction. Air entrainment also reduces segregation and bleeding, results in lower permeability, and increases cohesiveness and workability in structures where freezing and thawing are not factors.

The corrosion of reinforcing steel rates high among the chemical causes of deterioration of concrete in a marine environment. Such corrosion results from electro-chemical processes induced by the action of salts on the steel. Corrosion causes expansion and pressure which in turn causes concrete rupture and spalling along the plane of the reinforcing bars. Sea salts absorbed by rein-forced concrete produce corrosion cells wherein anodic (positive) and cathodic (negative) areas are established. Corrosion products formed on the anodic areas of the steel are sufficient to rupture the concrete. Such corrosion has occurred in concrete that is permeable due to a high water/cement ratio. It has also occurred in cases where there is insufficient concrete covering over the steel.

Another chemical cause of marine concrete deterioration is the use of reactive aggregates. Alkalies in cement often react with aggregates and certain types of shale, all of which contain hydrated silica, to form alkali-like silicates that may rupture and crack concrete. Such aggregates should be avoided, but if this is impossible then low alkali cement and a pozzolanic admixture will tend to re-duce the problem of excessive alkali-aggregate reaction. Some authorities believe that the use of low alkali cement alone is sufficient to avoid the reaction, thus eliminating the dangers of low early strength and the greater volume change in the concrete during wetting and drying which sometimes accompany the use of pozzolans.

Proper placement of marine concrete, especially with-in the tidal zone which is 2 feet below and above high tide, is also important in avoiding conditions leading to deterioration. Placement in this zone should be a continuous operation and horizontal joints and seams avoided whenever possible. If construction joints must be used the concrete should be left to harden

undisturbed. The bonding surface should then be cleaned thoroughly, cement grout broomed into the wet surface, and new concrete placed immediately.

The following practices are recommended to produce marine concrete of excellent durability:

- Proper mix proportions using the optimum cement content will yield a dense, impervious and relatively unabsorbent concrete.
- The optimum concrete and the water/cement ratio should not exceed cement to produce a mix that is plastic and workable.
- Reinforcing steel must have a minimum of 3 inches of concrete cover.
- Non-reactive aggregates should be used. The alternative is to compensate with low-alkali cement and/or pozzolans.
- An air entraining agent will reduce the danger of deterioration due to freezing and thawing.
- Especially at the tidal zone concrete should be placed in a continuous operation; if construction joints are necessary the bonding surface should be cleaned and grouted and new concrete placed immediately.
- Concrete should be compacted thoroughly to avoid honeycombing and to provide a dense, homogenous mass.

