Module -2: Fresh Concrete

Workability-factors affecting workability. Measurement of workability–slump, Compaction factor and Vee-Bee Consistometer tests, flow tests. Segregation and bleeding.

Process of manufacturing of concrete- Batching, Mixing, Transporting, Placing and Compaction. Curing – Methods of curing – Water curing, membrane curing, steam curing, accelerated curing, selfcuring.

Good and Bad practices of making and using fresh concrete and Effect of heat of hydration during mass concreting at project sites.

Workability of concrete

In general terms, workability represents the amount of work which is to be done to compact the compact the concrete in a given mould. The desired workability for a particular mix depends upon the type of compaction adopted and the complicated nature of reinforcement used in reinforced concrete. A workable mix should not segregate. The partial properties of workability are discussed below:

a. **Mixability:** It is the ability of the mix to produce a homogeneous green concrete from the constituent materials of the batch, under the action of the mixing forces. A less mixable concrete mix requires more time of mixing to produce a homogeneous and uniform mix.

b. **Transportability:** Transportability is the capacity of the concrete mix to keep the homogeneous concrete mix to keep the homogeneous concrete mix from segregating during a limited time period of transportation of concrete, when forces due to handling operations of limited nature act. Any segregation that is caused during the remaining operations that follow.

   In most of the countries, general recommendations for practice exist for transporting the concrete, which fact highlights the importance of this property.

c. **Mouldability:** It is the ability of the fresh concrete mix to fill completely the forms or moulds without losing continuity or homogeneity under the available techniques of placing the concrete at a particular job/ this property is complex, since the behavior of concrete is to be considered under dynamic conditions.

d. **Compactibility:** Compactibility is the ability of concrete mix to be compacted into a dense, compact concrete, with minimum voids, under the existing means of compaction at the site. The best mix from the point of view of compactibility should close the voids to an extent of 99% of the original voids present, when the concrete was placed in the moulds.

Factors affecting workability:

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

The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

a. Water content
b. Size of aggregates
c. Surface texture of aggregate
d. Use of admixtures
e. Mix proportions
f. Shape of aggregates
g. Grading of aggregates

a. **Water content:** Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. At the work site, supervisors who are not well versed with the practice of making good concrete resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at the site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

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

c. **Size of aggregate:** The bigger the size of the aggregate, the less the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates will give higher workability. The above of course will be true within certain limits.

d. **Shape of aggregates:** The shape of the aggregate influences the workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability to rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate.

The importance of shape of the aggregate will be of great significance in the case of present day high strength and high performance concrete when we use very low w/c in the order of about 0.25. We have already talked about that in years to come natural sand will be exhausted or costly. One has to go for manufactured sand. Shape of crushed sand

as available today is unsuitable but the modern crushers are designed to yield well shaped and well graded aggregates.

e. **Surface texture:** The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. From the earlier discussions it can be inferred that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

f. **Grading of aggregates:** This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.

g. **Use of admixtures:** Of all the factors mentioned above, the most important factor which affects the workability is the use of admixtures. It is to be noted that initial slump of concrete mix or what is called slump of reference mix should be about 2 – 3 cm to enhance the slump many fold at a minimum doze. Without initial slump of 2-3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.

Measurement of workability:

Slump Test

Objective: To determine the consistency of concrete mix of given proportions.

Scope and Significance

Unsupported fresh concrete flows to the sides and a sinking in height takes place. This vertical settlement is known as slump. In this test fresh concrete is filled into a mould of specified shape and dimensions, and the settlement or slump is measured when supporting mould is removed. Slump increases as *water-content* is increased. For different works different slump values have been recommended.

The slump is a measure indicating the *consistency or workability* of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not shown any segregation or bleeding. Segregation is said to occur when coarse aggregate tries to separate out from the finer material and a concentration of coarse aggregate at one place occurs. This results in large voids, less durability and strength. Bleeding of concrete is said to occur when excess water comes up at the surface of concrete. This causes small pores through the mass of concrete and is undesirable.

By this test we can determine the water content to give specified slump value. In this test water content is varied and in each case slump value is measured till we arrive at water content giving the required slump value.

This test is not a true guide to workability. For example, a harsh mix cannot be said to have same workability as one with a large proportion of sand even though they may have the same slump.

Apparatus

Iron pan to mix concrete, slump cone, spatula, trowels, tamping rod and graduated cylinder.

Slump test apparatus

Slump: true, shear and collapse

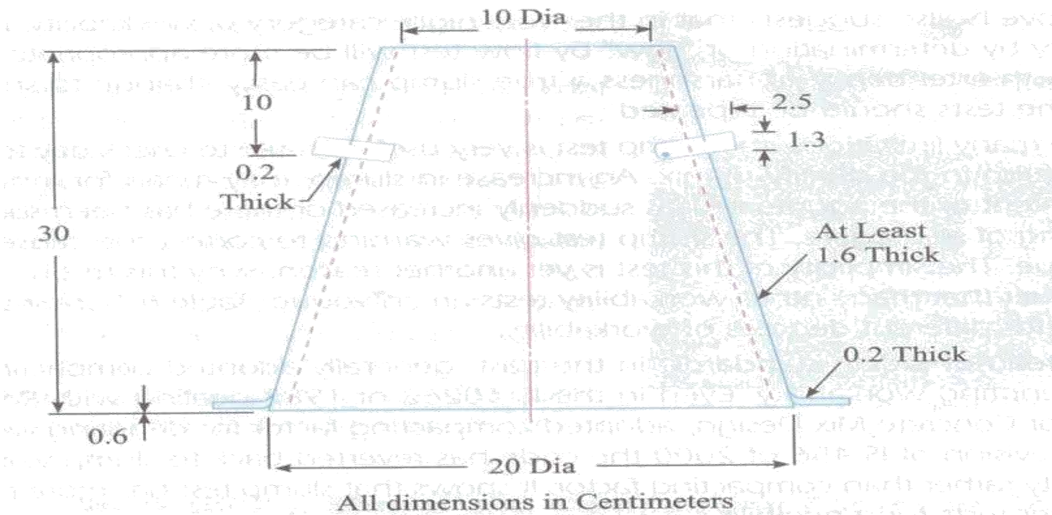
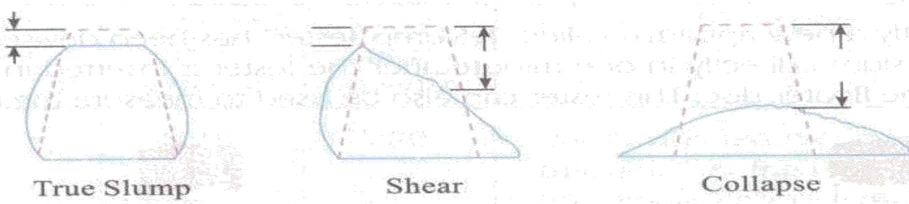


Fig. 6.1. Typical mould for Slump test.



Procedure

Four mixes are to be prepared with water-cement ratio (by mass) of 0.50, 0.60, 0.70 and 0.80, respectively, and for each mix take 10 kg of coarse aggregates, 5kg of sand and 2.5kg of cement with each mix proceed as follows

1) Mix the dry constituents thoroughly to get a uniform colour and then add water
2) Place the mixed concrete in the cleaned slump cone mould in 4 layers, each approximately ¼ of the height of the mould. Tamp each layer 25 times with tamping rod distributing the strokes in a uniform manner over the cross-section of the mould. For the second and subsequent layers the tamping rod should penetrate in to the underlying layer.
3) Strike off the top with a trowel or tamping rod so that the mould is exactly filled.
4) Remove the cone immediately, raising it slowly and carefully in the vertical direction.
5) As soon as the concrete settlement comes to a stop, measure the subsidence of concrete in mm which will give the slump.

Note: Slump test is adopted in the laboratory or during the progress of work in the field for determining consistency of concrete where nominal maximum size of aggregate does not exceed 40mm. Any slump specimen which collapses or shears off laterally gives incorrect results and if this occurs the test is repeated, only the true slump should be measured.

Observations & Calculations

Water-cement Ratio	Slump mm

Standard Values

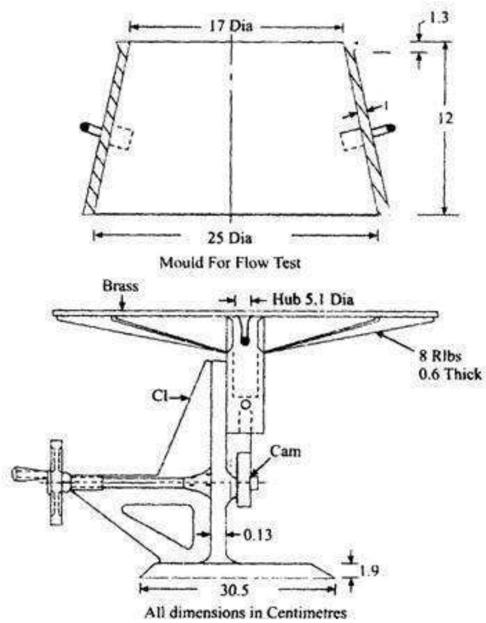
Sl.No.	Name of works	Slump, mm	Water-cement
1	Concrete for roads and mass concrete	25 to 50	0.70
2	concrete for R.C.C. beams andslabs	50 to 100	0.55
3	Columns and retaining walls	75 to 125	0.45
4	Mass concrete in foundation	25 to 50	0.70

Flow tests

Flow Test

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

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



Flow Table Apparatus

The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

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

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

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

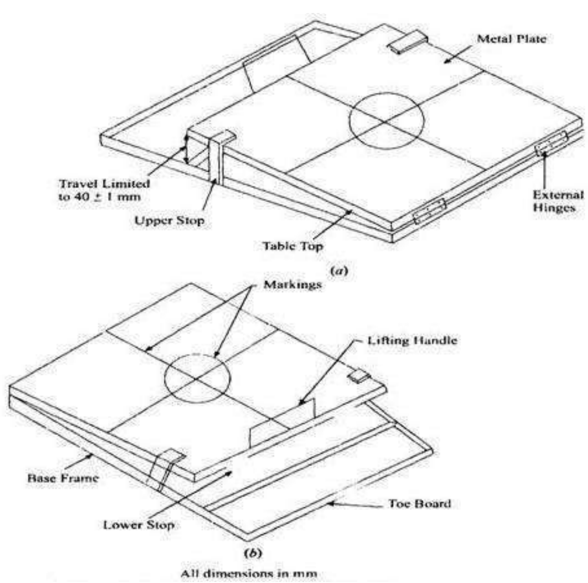
Flow Table Apparatus

The BIS has recently introduced another new equipment for measuring flow value of concrete. This new flow table test is in the line with BS 188 I part 105 of 1984 and DIN 1048 part I. The apparatus and method of testing is described below.

The flow table apparatus is to be constructed in accordance with Figure (a) and (b) Flow table top is constructed from a flat metal of minimum thickness 1.5 mm. The top is in plan 700 mm x 700 mm. The centre of the table is marked with a cross, the lines which run paralled to and out to the edges of the plate, and with a central circle 200 mm in diameter. The front of the flow table top is provided with a lifting handle as shown in Fig (b) The total mass of the flow table top is about 16 ± 1 kg.

The flow table top is hinged to a base frame using externally mounted hinges in such a way that no aggregate can become trapped easily between the hinges or hinged surfaces. The front of the base frame shall extend a minimum 120 mm beyond the flow table top in order to provide a top board. An upper stop similar to that shown in Fig (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± I mm.

The lower front edge of the flow table top is provided with two hard rigid stops which transfer the load to the base frame. The base frame is so constructed that this load is then transferred directly to the surface on which the flow table is placed so that there is minimal tendency for the flow table top to bounce when allowed to fall.



Flow table apparatus (as per IS 9103 of 1999)

Compaction Factor Test

Objective: To determine the workability of concrete mix of given proportions by the compaction factor test.

Scope and Significance

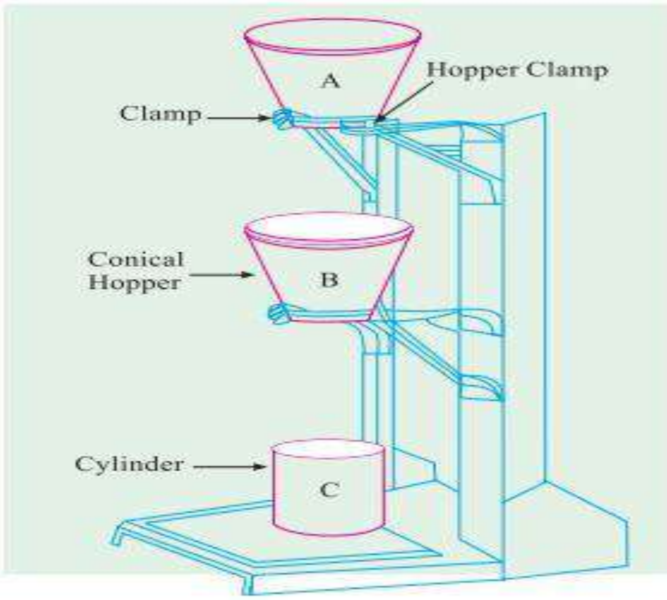
Compaction factor test is adopted to determine the workability of concrete, where nominal size of aggregate does not exceed 40mm, and is primarily used in laboratory. It is based upon the definition, that workability is that property of the concrete which determines the amount of work required to produce *full compaction*. The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction. To find the workability of freshly prepared concrete, the test is carried out as per specification of IS: 1199-1959. Workability gives an idea of the capability of being worked, i.e., idea to control the quantity of water in cement concrete mix to get uniform strength.

It is more sensitive and precise than slump test and is particularly useful for concrete mixes of low workability. The compaction factor (C.F.) test is able to indicate small variations in workability over a wide range.

Apparatus

Compaction factor apparatus, trowels, Graduated cylinder, balance, tamping rod and iron buckets

Compaction factor test apparatus



Compacting Factor Apparatus

Essential dimension of the compacting factor apparatus for use with aggregate not exceeding 40 mm Nominal Maximum Size.

Upper hopper A	
Top internal diameter	25.4
Bottom internal diameter	12.7
Internal height	27.9
Lower hopper B	
Top internal diameter	22.9
Bottom internal diameter	12.7

Internal height	**22.9**
Cylinder C	
internal diameter	**15.2**
Internal height	**30.5**
Distance between bottom of upper hopper and top of lower hopper	**20.3**
Distance between bottom of lower hopper and top cylinder	**20.3**

Procedure

1. Keep the compaction factor apparatus on a level ground and apply grease on the inner surface of the hoppers and cylinder.
2. Fasten the flap doors.
3. Weigh the empty cylinder accurately and note down the mass as W_1 kg.
4. Fix the cylinder on the base with fly nuts and bolts in such a way that the central points of hoppers and cylinder lie on one vertical line. Cover the cylinder with a plate.

5. Four mixes are to be prepared with water-cement ratio (by mass) 0.50, 0.60, 0.70, and 0.80, respectively. For each mix take 9 kg of aggregate, 4.5 kg sand 2.25 kg of cement. With each mix proceed as follows:
   a) Mix sand and cement day, until a mixture of uniform colour is obtained. Now mix the coarse aggregate and cement-sand mixture until coarse aggregate is uniformly distributed throughout the batch.
   b) Add the required amount of water to the above mixture and mix it thoroughly until concrete appears to be homogeneous.
6. Fill the freshly mixed concrete in upper hopper gently and crefully with hand scoop without compacting.
7. After two minutes, release the trap door so that the concrete may fall into the lower hopper brining the concrete into standard compaction.
8. Immediately after the concrete has come to rest, open the trap door of lower hopper

and allow the concrete to fall into the cylinder bringing the concrete into standard compaction.

9. Remove the excess concrete above the top of the cylinder by a pair of trowels, one in each hand will blades horizontal slide them from the opposite edges of the mould inward to the centre with a sawing motion.
10. Clean the cylinder from all sides properly. Find the mass of partially compacted concrete thus filled in the cylinder, say W_2 kg.
11. Refill the cylinder with the same sample of concrete in approximately 50mm layers, vibrating each layer heavily so as to expel all the air and obtain full compaction of the concrete.
12. Struck off level the concrete and weigh and cylinder filled with fully compacted concrete. Let the mass be W_3 kg.

Observations, Calculations & Results

Mass of cylinder W1 = ………

Sl. No.	**Water-Cement ratio**	**Mass with partially Compacted Concrete**	**Mass with Fully Compacted concrete**	**Mass of Partially compacted concrete W_2-W_1**	**Mass of fully Compacted Concrete**	**C.F.= $\frac{W_2-W_1}{W_3-W_1}$**
		W_2	**W_3**		**W_3-W_1**	
1	0.50					
2	0.60					
3	0.70					
4	0.80					

Standard Values of Workability, Slump and Compacting Factor of Concretes with 20 mm or 40 mm Maximum size of Aggregate

Degree of workability	**Compacting factor**		**Use for which concrete is suitable**
	Small apparatus	**Large apparatus**	

Very low	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may compacted in certain cases with hand operated machines.
Low	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	0.92	0.935	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration
High	0.95	0.96	For sections with congested reinforcement. normally suitable for vibration.

Workability By Vee-Bee Consistometer

Objective

To determine the workability of freshly mixed concrete by the use of Vee - Bee consistometer.

Scope and Significance

The workability of fresh concrete is a composite property, which includes the diverse requirements of stability, mobility, compactability, placeability and finishability. There are different methods for measuring the workability. Each of them measures only a particular aspect of it and there is really no unique test, which measures workability of concrete in its totality. This test gives an indication of the mobility and to some extent of the compactibility of freshly mixed concrete.

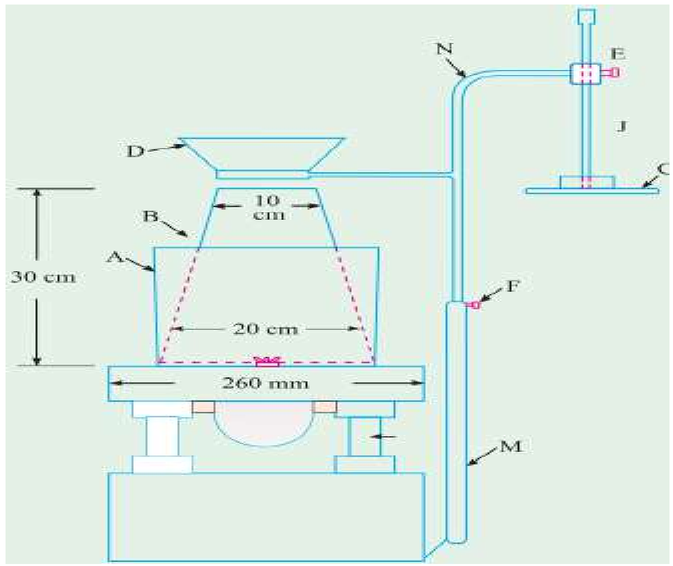
The test measures the relative effort required to change a mass of concrete from one definite shape to another (i.e., from conical to cylindrical) by means of vibration. The amount of effort called remoulding effort is taken as the time in seconds required to complete the change. The results of this test are of value in studying the mobility of the masses of concrete made with varying amounts of water, cement and with various types of gradings of aggregate.

The time required for complete remoulding in seconds is considered as a measure of workability and is expressed as the number of Vee-Bee seconds. The method is suitable for dry concrete. For concrete of slump in excess of 50mm, the remoulding is so quick that the time cannot measured.

Apparatus

Cylindrical container, Vee-Bee apparatus (consisting of vibrating table, slump cone) standard iron rod, weighing balance and trowels.

Vee – Bee Consistometer



Procedure

(1) Place the slump cone in the cylindrical container of the consistometer. Fill the cone in four layers, each approximately one quarter of the height of the cone. Tamp each layer with twenty-five strokes of the rounded end of the tamping rod. The strokes are distributed in a uniform manner over the cross-section of the cone and for the second and subsequent layers the tamping bar should penetrate into the underlying layer. After the top layer has been rodded, struck off level the concrete with a trowel so that the cone is exactly filled.

(2) Move the glass disc attached to the swivel arm and place it just on the top of the slump cone in the cylindrical container. Adjust the glass disc so as to touch the top of the concrete cone, and note the initial reading on the graduated rod.

(3) Remove the cone from the concrete immediately by raising it slowly and carefully in the vertical direction. Lower the transparent disc on the top of concrete. Note down the reading on the graduated rod.

(4) Determine the slump by taking the difference between the readings on the graduated rod recorded in the steps (2) and (3) above.

(5)

(6) Switch on the electrical vibrations and start the stopwatch. Allow the concrete to remould by spreading out in the cylindrical container. The vibrations are continued until the concrete is completely remoulded, i.e, the surfaces becomes horizontal and the whole concrete surface adheres uniformly to the transparent disc.

(7) Record the time required for complete remoulding seconds which measures the workability expressed as number of Vee-Bee seconds.

Observations and Calculation

Initial reading on the graduated rod, a		
Final reading on the graduated rod, b		
Slump (b) – (a) , cm		
Time for complete remoulding, seconds		

Results

The consistency of the concrete is ………….

Standard Values

Workability desciption	Vee-Bee Time, Seconds
Extremely dry	32-18
Very stiff	18-10
Stiff	10-5
Stiff plastic	5-3
Plastic	3-0
Flowing	----

Segregation:

Segregation is defined as the separation of the constituents of a homogeneous mixture of concrete. It is caused by the differences in sizes and weights of the constituent particles. Segregation can be controlled by properly choosing the grading of aggregates and by carefully handling wet mixes. In relatively lean and dry mixes, segregation can be caused by the coarser particles separating out because they travel farther along the slope or settle to a greater extent than finer particles. The second form of segregation occurs in very wet mixes in which the cement – water paste separates from the mix.

Segregation can also be caused by poor handling, such as dropping wet concrete from a considerable height, passing long chutes along a slope, and discharging concrete carelessly against some firm obstruction. It may also be caused by the vibration of concrete. Though vibration provides a useful means of compaction, over – vibration leads to segregation. This can happen when vibration is allowed to continue for too long. It leads to the separation of coarse aggregates from the mix. These aggregates settle at the bottom, and the cement – water paste moves to the top in the form of laitance (scum). This laitance is different from bleed water.

Segregation is difficult to measure. However, its occurrence is easily detected. The flow test can indicate the susceptibility of a mix that is likely to segregate. In dry mixes, heavier particles move away and occupy the edges of the flow table. In wet mixes, the cement paste trends to move away from the middle and the centre of the flow table is left only with coarser particles.

Bleeding:

Bleeding is also known as „water gain". It is the accumulation of water at the surface, which accompanies the sedimentation of freshly mixed concrete. This happens due to the inability of the solid constituents of the mix to hold all the mixing water and they settle downwards due to gravity and the water moves upwards.

Bleeding is expressed quantitatively as the total settlement per unit height of concrete or as the percentage of mixing water. In extreme cases, this can be nearly 20%. Bleeding is a function of (a) air velocity, (b) temperature, and (c) humidity. If the rate of bleeding is roughly equal to the rate of evaporation, then bleeding will not cause any problem. If the rate of bleeding is less than the rate of evaporation, then the surface becomes dry, because of which cracks appear on it. The restraint at the bottom encourages such cracks. The evaporation of water from the surface of concrete depends on (a) the relative humidity of the surrounding air, (b) the ambient temperature, and (c) the velocity of wind.

Process of Manufacture of Concrete:

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredients of good concrete and bad concrete are the same. If meticulous 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. Therefore, it is necessary for us to know what are the good rules to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

a. Batching
b. Mixing
c. Transporting
d. Placing
e. Compacting
f. Curing
g. Finishing.

Batching:

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

a. Volume batching
b. Weigh batching

a. **Volume batching:**

Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The amount of solid granular material in a cubic metre is an indefinite quantity. Because of this, for quality concrete material has to be measured by weight only. However, for unimportant concrete or for any small job, concrete may be batched by volume.

Cement is always measured by weight. It is never measured in volume. Generally, for each batch mix, one bag of cement is used. The volume of one bag of cement is taken as thirty five (35) litres. Gauge boxes are used for measuring the fine and coarse aggregates.
Water is measured either in kg or litres as may be convenient. The quantity of water required is a product of water/cement ratio and the weight of cement; for example, if the water/cement ratio of 0.5 is specified, the quantity of mixing water required per bag of cement is 0.5 x 50.00 = 25 kg or 25 litres. The quantity is, of coarse, inclusive of any surface moisture sent in the aggregate.

b. **Weigh Batching:**

Strictly speaking, weigh batching is the correct method of measuring the materials. For important concrete, invariably, weigh batching system should be adopted. Use of weight system in batching, facilitates accuracy, flexibility and simplicity. Different types of weigh batchers are available, the particular type to be used, depends upon the nature of job. Large weigh batching plants have automatic weighing equipment. The use of this automatic equipment for batching is one of sophistication and requires qualified and experienced engineers. In this, further complication will come to adjust water content to cater for the moisture content in the aggregate. In smaller works, the weighing arrangement consists of two weighing buckets, each connected through a system of levers to spring-loaded dials which indicate the load. The weighing buckets are mounted on a central spindle about which they rotate. Thus one can be loaded while the other is being discharged into the mixer skip. A simple spring balance or the common platform weighing machines also can be used for small jobs.

On large work sites, the weigh bucket type of weighing equipments is used. This fed from a large overhead storage hopper and it discharges by gravity, straight into the mixer. The weighing is done through a lever-arm system and two interlinked beams and jockey weights. The required quantity of say, coarse aggregate is weighed, having only the lower beam in after balancing, by turning the smaller lever, to the left of the beam, the two beams are interlinked and the fine aggregate is added until they both balance. The final balance is indicated by the pointer on the scale to the right of the beams. Discharge is through the swivel gate at the bottom.

Automatic batching plants are available in small or large capacity. In this, the operator press one or two buttons to put into motion the weighing of all the different materials, the flow of each being cut off when the correct weight is reached. In their most advanced forms, automatic plants are electrically operated on a punched card system. This type of plant is particularly only suitable for the production of ready-mixed concrete in which very frequent changes in mix proportion have to be made to meet the varying requirements of different customers.

In some of the recent automatic weigh batching equipments, recorders are fitted which record graphically the weight of each material, delivered to each batch. They are meant to record, and check the actual and designed proportions.

Aggregate weighing machines require regular attention if they are to maintain their accuracy. Check calibrations should always be made by adding weights in the hopper equal to the full weight of the aggregate in the batch. The error found is adjusted from time to time.

In small jobs, cement is often not weighed; it is added in bags assuming the weight of the bag as 50 kg. In reality, though the cement bag is made of 50 kg. At the factory, due to transportation, handling at a number of places, it loses some cement, particularly when jute bags are used. In fact, the weight of a cement bag at the site is considerably less. Sometimes, the loss of weight becomes more than 5 kg. This is one of the sources of error in volume batching and also in weigh batching, when the cement is not actually weighed. But in important major concreting jobs, cement is also actually weighed and the exact proportion as designed is maintained.

Measurement of Water:

When weigh batching is adopted, the measurement of water must be done accurately. Addition of water by graduated bucket in terms of litres will not be accurate enough for the reason of spillage of water etc. It is usual to have the water measured in a horizontal tank or vertical tank fitted to the mixer. These tanks are filled up after every batch. The filling is so designed to have a control to admit any desired quantity of water. Sometimes, water- meters are fitted in the main water supply to the mixer from which the exact quantity of water can be let into the mixer.

In modern batching plants sophisticated automatic microprocessor controlled weigh batching arrangements, not only accurately measures the constituent materials, but also the moisture content of aggregates.

Moisture content is automatically measured by sensor probes and corrective action is taken to deduct that much quantity of water contained in sand from the total quantity of water. A number of such sophisticated batching plants are working in our country, for the last 4-5 years.

Mixing:

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

a. Hand Mixing
b. Machine mixing

a. **Hand Mixing:** Hand mixing is practised for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.

Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers. Pour the cement on the top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved. This uniform mixture is spread out in thickness of about 20 cm. Water is taken in a water-can 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. It is of particular importance to see that the water is not poured but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the just required consistency. At that stage, even a small quantity of water makes difference.

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

Many types of mixers are available for mixing concrete. They can be classified as batch-mixers and continuous mixers. Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working. In this, materials are fed continuously by screw feeders and the materials are continuously mixed and continuously discharged. These types of mixers are used in large works such as dams. In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type. The drum type may be further classified as tilting, non-tilting, reversing or forced action type

Very little is known about the relative mixing efficiencies of the various types of mixers, but some evidences are there to suggest that pan mixers with a revolving star of blades are more efficient. They are specially suitable for stiff and lean mixes, which present difficulties with most other types of mixers, mainly due to sticking of mortar in the drum. The shape of the drum, the angle and size of blades, the angle at which the drum is held, affect the efficiency of mixer. It is seen that tilting drum to some extent is more efficient than non-tilting drum. In non-tilting drum for discharging concrete, *a* chute is introduced into the drum by operating a lever.

The concrete which is being mixed in the drum, falls into the inclined chute and gets discharged out. It is seen that a little more of segregation takes place, when a non-tilting mixer is used. It is observed in practice that, generally, in any type of mixer, even after thorough mixing in the drum, while it is discharged, more of coarse aggregate comes out first and at the end matrix gets discharged. It is necessary that a little bit of re-mixing is essential, after discharged from mixer, on the platform to off-set the effect of segregation caused while concrete is discharged from the mixer.

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

a. Tilting: 85 T, 100 T, 140 T, 200 T
b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT
c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

The letters T, NT, R denote tilting, non-tilting and reversing respectively. Normally, a batch of concrete is made with ingredients corresponding to 50 kg cement. If one has a choice for indenting a mixer, one should ask for such a capacity mixer that should hold all the materials for one bag of cement. This of course, depends on the proportion of the mix. For example, for 1 : 2 : 4 mix, the ideal mixer is of 200 litres capacity, whereas if the ratio is 1 : 3 : 6, the requirement will be of 280 litres capacity to facilitate one bag mix. Mixer of 200 litres capacity is insufficient for 1: 3: 6 mix and also mixer of 280 litres is too big, hence uneconomical for 1: 2: 4 concrete.

To get better efficiency, the sequence of charging the loading skip is as under:

Firstly, about half the quantity of coarse aggregate is placed in the skip over which about half the quantity of fine aggregate is poured. On that, the full quantity of cement *i . e* , one bag is poured over which the remaining portion of coarse aggregate and fine aggregate is deposited in sequence. This prevents spilling of cement, while discharging into the drum and also this prevents the blowing away of cement in windy weather.

Before the loaded skip is discharged to the drum, about 25 per cent of the total quantity of water required for mixing is introduced into the mixer drum to wet the drum and to prevent any cement sticking to the blades or at the bottom of the drum.

Immediately, on discharging the dry material into the drum, the remaining 75 per cent of water is added to the drum. If the mixer has got an arrangement for independent feeding of water, it is desirable that the remaining 75 per cent of water is admitted simultaneously along with the other materials. The time is counted from the moment all the materials, particularly; the complete quantity of water is fed into the drum.

Reversible drum concrete mixer / mini batching plant

When plasticizer or super plasticizer is used, the usual procedure could be adopted except that about one litre of water is held back. Calculated quantity of plasticizer or super plasticizer is mixed with that one litre of water and the same is added to the mixer drum after about one minute of mixing. It is desirable that concrete is mixed little longer (say 1/2 minute more) so that the plasticizing effect is fully achieved by proper dispersion.

When plasticizers are used, generally one has to do number of trials in the laboratory for arriving at proper dosage and required slump. Small scale laboratory mixers are inefficient and do not mix the ingredients properly. Plasticizers in small quantity do not get properly dispersed with cement particles. To improve the situations, the following sequence may be adopted.

Mixing Time:

Concrete mixers are generally designed to run at a speed of 15 to 20 revolutions per minute. For proper mixing, it is seen that about 25 to 30 revolutions are required in a well designed mixer. In site, the normal tendency is to speed up the outturn of concrete by reducing the mixing time. This results in poor quality of concrete. On the other hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption.

Therefore, it is of importance to mix the concrete for such a duration which will accrue optimum benefit. It is seen from the experiments that the quality of concrete in terms of compressive strength will increase with the increase in the time of mixing, but for mixing time beyond two minutes, the improvement in compressive strength is not *very* significant. Concrete mixer is not a simple apparatus. Lot of considerations have gone as input in the design of the mixer drum. The shape of drum, the number of blades, inclination of blades with respect to drum surface, the length of blades, the depth of blades, the space between the drum and the blades, the space between metal strips of blades and speed of rotation etc., are important to give uniform mixing quality and optimum time of mixing.

Generally mixing time is related to the capacity of mixer. The mixing time varies between 1 ° to 2° minutes. Bigger the capacity of the drum more is the mixing time. However, modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. One cubic meter capacity high speed Pan Mixer takes only about 2 minutes for batching and mixing. The batching plant takes about 12 minutes to load *a* transit mixer of 6 m^3 capacity.

Sometimes, at a site of work concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time, as for instance when some quarrel or dispute takes place with the workers, or when unanticipated repair or modification is required to be done on the formwork and reinforcement. Long-time mixing of concrete will generally result in increase of compressive strength of concrete within limits. Due to mixing over long periods, the effective water/cement ratio gets reduced, owing to the absorption of water by aggregate and evaporation. It is also possible that the increase in strength may be due to the improvement in workability on account of excess of fines, resulting from the abrasion and attrition of coarse aggregate in the mix, and from the coarse aggregates themselves becoming rounded. The above may not be true in all conditions and in all cases. Sometimes, the evaporation of water and formation of excess fines may reduce the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

Modern ready mixed concrete plant.

In case of long haul involved in delivering ready-mixed concrete to the site of work, concrete is mixed intermittently to reduce the bad effect of continuous mixing. A pertinent point to note in this connection is that when the concrete is mixed or agitated from time to time with a short interval, the normal rule of initial setting time is not becoming applicable. The concrete that is kept in agitation, does not exactly follow the setting time rule as applicable to concrete kept in an unagitated and quiescent condition.

Transporting of concrete:

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

a. Mortar Pan
b. Crane, Bucket and Rope way
c. Belt Conveyors

d. Skip and Hoist
e. Pump and Pipe line
f. Wheel Barrow, Hand Cart
g. Truck mixer and Dumpers
h. Chute
i. Tansit Mixer

Mortar Pan:

Use of mortar pan for transportation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case, concrete is carried in small quantities. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulties.

Wheel barrow:

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

Crane, Bucket and Rope Way:

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

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

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

Truck Mixer and Dumpers:

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

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

Belt Conveyors:

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

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

Chute:

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

Transporting and placing concrete by chute

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

Skip and Hoist:

This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging and human ladder for transporting concrete is not normally possible for more than 3 or 4 storeyed building constructions. For laying concrete in taller structures, chain hoist or platform hoist or skip hoist is adopted. At the ground level, mixer directly feeds the skip and the skip travel up over rails upto the level where concrete is required. At that point, the skip discharges the concrete automatically or on manual operation. The quality of concrete *i.e.* the freedom from segregation will depend upon the extent of travel and rolling over the rails. If the concrete has travelled a considerable height, it is necessary that concrete on discharge is required to be turned over before being placed finally

Tower Hoist and Winch, for lifting concrete to higher level.

Transit Mixer:

Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMCJ. In India, today (2000 AD) there are about 35 RMC plants and a number of central batching plants are working. It is a fair estimate that there are over 600 transit mixers in operation in India. They are truck mounted having a capacity of 4 to 7 m^3. 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 the 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 the concrete at site.

Transit-mixing permits longer haul and are less vulnerable in case of delay. The truck mixer the speed of rotating of drum is between 4 -16 revolutions per minute. A limit of 300 revolutions for both agitating and mixing is laid down by ASTM C 94 or alternatively, the concretes must be placed within 14- of mixing. In case of transit mixing, water need not be added till such time the mixing is commenced BS 5328 - 1991, restrict the time of 2 hours during which, cement and moist sand are allowed to remain in contact. But the above restrictions are to be on the safe side. Exceeding these limit is not going to be harmful if the mix remains sufficiently workable for full compaction.

Transit Mixer, a popular mathod of transporting concrete over a long distance.

With the development of twin fin process mixer, the transit mixers have become more efficient in mixing. In these mixers, in addition to the outer spirals, have two opposed inner spirals. The outer spirals convey the mix materials towards the bottom of the drum, while the opposed mixing spirals push the mix towards the feed opening. The repeated counter current mixing process is taking place within the mixer drum Sometimes a small concrete pump is also mounted on the truck carrying transit mixer.

This pump, pumps the concrete discharged from transit mixer. Currently we have placer boom also as part of the truck carrying transit mixer and concrete pump and with their help concrete is transported, pumped and placed into the formwork of a structure easily.

Pumping arrangements

Placing Concrete:

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

a. Placing concrete within earth mould.
b. (Example: Foundation concrete for a wall or column).
c. Placing concrete within large earth mould or timber plank formwork.
d. (Example: Road slab and Airfield slab).
e. Placing concrete in layers within timber or steel shutters.
f. (Example. Mass concrete in dam construction or construction of concrete abutment or pier).
g. Placing concrete within usual from work.
h. (Example: Columns, beams and floors).
i. Placing concrete under water.

Concrete is invariably laid as foundation bed below the walls or columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed. Any root of trees passing through the foundation must be cut, charred or tarred effectively to prevent its further growth and piercing the concrete at a later date. The surface of the earth, if dry, must be just made damp so that the earth does not absorb water from concrete.

On the other hand if the foundation bed is too wet and rain-soaked, the water and slush must be removed completely to expose firm bed before placing concrete. If there is any seepage of water taking place into the foundation trench, effective method for diverting the flow of water must be adopted before concrete is placed in the trench or pit.

Placing concrete by pump and placing boom

Often concrete is required to be poured from a greater height. When the concrete is poured from a height, against reinforcement and lateral ties, it is likely to segregate or block the space to prevent further entry of concrete. To avoid this, concrete is directed by tremie, drop chute or by any other means to direct the concrete within the reinforcement and ties. Sometimes, when the formwork is too narrow, or reinforcement is too congested to allow the use of tremie or drop chute, a small opening in one of the sides is made and the concrete is introduced from this opening instead of pouring from the top. It is advisable that care must be taken at the stage of detailing of reinforcement for the difficulty in pouring concrete. In long span bridges the depth of prestressed concrete girders may be of the order of even 4-5 meters involving congested reinforcement. In such situations planning for placing concrete in one operation requires serious considerations on the part of designer.

Form work:

Form work shall be designed and constructed so as to remain sufficiently rigid during placing and compaction of concrete. The joints are plugged to prevent the loss of slurry from concrete.

Stripping Time:

Formwork should not be removed until the concrete has developed a strength of at least twice the stress to which concrete may be subjected at the time of removal of formwork. In special circumstances the strength development of concrete can be assessed by placing companion cubes near the structure and curing the same in the manner simulating curing conditions of structures. In normal circumstances, where ambient temperature does not fall below I 5°C and where ordinary Portland cement is used and adequate curing is done.

Compaction of Concrete:

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

If this air is not removed fully, the concrete loses strength considerably. In order to achieve full compaction and maximum density, with reasonable compacting efforts available at site, it is necessary to use a mix with adequate workability. It is also of common knowledge that the mix should not be too wet for easy compaction which also reduces the strength of concrete. For maximum strength, driest possible concrete should be compacted 100 per cent. The overall economy demands I 00 per cent compaction with a reasonable compacting efforts available in the field.

The following methods are adopted for compacting the concrete:

a. Hand Compaction
   i. Rodding
   ii. Ramming
   iii. Tamping

b. Compaction by Vibration
   i. Internal vibrator (Needle vibrator)
   ii. Formwork vibrator (External vibrator)
   iii. Table vibrator
   iv. Platform vibrator
   v. Surface vibrator (Screed vibrator)
   vi. Vibratory Roller.

c. Compaction by Pressure and Jolting

d. Compaction by Spinning.

Hand Compaction:

Hand compaction of concrete is adopted in case of unimportant concrete work of small magnitude. Sometimes, this method is also applied in such situation, where a large quantity of reinforcement is used, which cannot be normally compacted by mechanical means. Hand compaction consists of rodding, ramming or tamping. When hand compaction is adopted, the consistency of concrete is maintained at a higher level. The thickness of the layer of concrete is limited to about 15 to 20 cm. Rodding is nothing but poking the concrete with about 2 metre long, 16 mm diameter rod to pack the concrete between the reinforcement and sharp corners and edges. Rodding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes, instead of iron rod, bamboos or cane is also used for rodding purpose.

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

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

Compaction by Vibration:

It is pointed out that the compaction by hand, if properly carried out on concrete with sufficient workability, gives satisfactory results, but the strength of the hand compacted concrete will be necessarily low because of higher water cement ratio required for full compaction.

Where high strength is required, it is necessary that stiff concrete, with low water/cement ratio be used. To compact such concrete, mechanically operated vibratory equipment, must be used. The vibrated concrete with low water/cement ratio will have many advantages over the hand compacted concrete with higher water/cement ratio.

The modern high frequency vibrators make it possible to place economically concrete which is impracticable to place by hand. A concrete with about 4 cm slump can be placed and compacted fully in a closely spaced reinforced concrete work, whereas, for hand compaction, much higher consistency say about 12 cm slump may be required. The action of vibration is to set the particles of fresh concrete in motion, reducing the friction between them and affecting a temporary liquefaction of concrete which enables easy settlement.

While vibration itself does not affect the strength of concrete which is controlled by the water/cement ratio, it permits the use of less water. Concrete of higher strength and better quality can, therefore, be made with a given cement factor with less mixing water. Where only a given strength is required, it can be obtained with leaner mixes than possible with hand compaction, making the process economical. Vibration, therefore, permits improvement in the quality of concrete and in economy

Double beam screed board vibrator

Compaction of concrete by vibration has almost completely revolutionized the concept of concrete technology, making possible the use of low slump stiff mixes for production of high quality concrete with required strength and impermeability. The use of vibration may be essential for the production of good concrete where the congestion of the reinforcement or the inaccessibility of the concrete in the formwork is such that hand compaction methods are not practicable. Vibration may also be necessary if the available aggregates are of such poor shape and texture which would produce a concrete of poor workability unless large amount of water and cement is used. In normal circumstances, vibration is often adopted to improve the compaction and consequently improve the durability of structures. In this way, vibration can, under suitable conditions, produce better quality concrete than by hand compaction Lower cement content and lower water-cement ratio can produce equally strong concrete more economically than by hand compaction.

Although vibration properly applied is a great step forward in the production of quality concrete, it is more often employed as a method of placing ordinary concrete easily than as a method for obtaining high grade concrete at an economical cost. All the potential advantages of vibration can be fully realized only if proper control is exercised in the design and manufacture of concrete and certain rules are observed regarding the proper use of different types of vibrators.

Internal Vibrator:

Of all the vibrators, the internal vibrator is most commonly used. This is also called, "Needle Vibrator", "Immersion Vibrator", or "Poker Vibrator". This essentially consists of a power unit, a flexible shaft and a needle. The power unit may be electrically driven or operated by petrol engine or air compressor. The vibrations are caused by eccentric weights attached to the shaft or the motor or to the rotor of a vibrating element Electromagnet, pulsating equipment is also available. The frequency of vibration varies upto 12,000 cycles of vibration per minute.

The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. The bigger needle is used in the construction of mass concrete dam. Sometimes, arrangements are available such that the needle can be replaced by a blade of approximately the same length. This blade facilitates vibration of members, where, due to the congested reinforcement, the needle would not go in, but this blade can effectively vibrate. They are portable and can be shifted from place to place very easily during concreting operation. They can also be used in difficult positions and situations.

Formwork Vibrator (External Vibrator):

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

Table Vibrator:

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

Platform Vibrator:

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

Surface Vibrator:

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

Compaction by Pressure and Jolting:

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

Compaction by Spinning:

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

Vibratory Roller:

One of the recent developments of compacting very dry and lean concrete is the use of Vibratory Roller. Such concrete is known as Roller Compacted Concrete. This method of concrete construction originated from Japan and spread to USA and other countries mainly for the construction of dams and pavements. Heavy roller which vibrates while rolling is used for the compaction of dry lean concrete. Such roller compacted concrete of grade M 10 has been successfully used as base course, 15 cm thick, for the Delhi-Mathura highway and Mumbai-Pune express highways.

Curing of Concrete

Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of course, the rate of hydration is fast to start with, but continues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23for hydration and *a* water/cement ratio of 0.1 5 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water cement ratio of 0.38 would satisfy the requirement of water for hydration and at the same time no capillary vavities would be left. However; it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

Cracks on concrete surface due to inadequate curing

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

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

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

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

The quick surface drying of concrete results in the movement of moisture from the interior to the surface. This steep moisture gradient cause high internal stresses which are also responsible for internal micro cracks in the semi-plastic concrete. Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough water curing.

Curing Methods:

Curing methods may be divided broadly into four categories:

a. Water curing
b. Membrane curing
c. Application of heat
d. Miscellaneous

Water Curing:

This is by far the best method of curing as it satisfies all the requirements of curing, namely, promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. It is pointed out that even if the membrane method is adopted, it is desirable that a certain extent of water curing is done before the concrete is covered with membranes.

Water curing can be done in the following ways:

a. Immersion
b. Ponding
c. Spraying or Fogging
d. Wet covering

The precast concrete items are normally immersed in curing tanks for certain duration. Pavement slabs, roof slab etc. are covered under water by making small ponds. Vertical retaining wall or plastered surfaces or concrete columns etc. are cured by spraying water. In some cases, wet coverings such as wet gunny bags, hessian cloth, jute matting, straw etc., are wrapped to vertical surface for keeping the concrete wet. For horizontal surfaces saw dust, earth or sand are used as wet covering to keep the concrete in wet condition for a longer time so that the concrete is not unduly dried to prevent hydration.

Membrane Curing:

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

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

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

Bituminous compound being black in colour absorbs heat when it is applied on the top surface of the concrete. This results in the increase of temperature in the body of concrete which is undesirable. For this purpose, other modified materials which are not black in colour are in use. Such compounds are known as "Clear Compounds". It is also suggested that a lime wash may be given over the black coating to prevent heat absorption.

Membrane curing by spraying

Membrane curing is a good method of maintaining a satisfactory state of wetness in the body of concrete to promote continuous hydration when original water/cement ratio used is not less than 0.5. To achieve best results, membrane is applied after one or two days' of actual wet curing. Since no replenishing of water is done after the membrane has been applied it should be ensured that the membrane is of good quality and it is applied effectively. Two or three coats may be required for effective sealing of the surface to prevent the evaporation of water.

Increase in volume of construction, shortage of water and need for conservation of water, increase in cost of labour and availability of effective curing compounds have encouraged the use of curing compounds in concrete construction. Curing compound is an obvious choice for curing canal lining, sloping roofs and textured surface of concrete pavements.

It is seen that there are some fear and apprehension in the mind of builders and contractors regarding the use of membrane forming curing compounds. No doubt that curing compounds are not as efficient and as ideal as water curing. The efficiency of curing compounds can be at best be 80% of water curing. But this 80% curing is done in a foolproof manner. Although water curing is ideal in theory, it is often done intermittently and hence, in reality the envisaged advantage is not there, in which case membrane curing may give better results.

When waterproofing paper or polyethylene film are used as membrane, care must be taken to see that these are not punctured anywhere and also see whether adequate laping is given at the junction and this lap is effectively sealed.

Curing vertical surface by wet covering.

Application of Heat:

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

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

a. Concrete is vulnerable to damage only for short time.
b. Concrete member can be handled very quickly.
c. Less space will be sufficient in the casting yerd.
d. A smaller curing tank will be sufficient.
e A higher outturn is possible for a given capital outlay.
f . The work can be put on to service at a much early time,
g . A fewer number of formwork will be sufficient or alternatively with the given number of formwork more outturn will be achieved.
h. Prestressing bed can be released early for further casting.

From the above mentioned advantages it can be seen that steam curing will give not only economical advantages, but also technical advantages in the matter of prefabrication of concrete elements.

The exposure of concrete to higher temperature is done in the following manner:

a. Steam curing at ordinary pressure.
b. Steam curing at high pressure.
c. Curing by Infra-red radiation.
d. Electrical curing.

Steam curing at ordinary pressure:

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

Beam under steam curing

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

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

It is interesting to note that concrete subjected to higher temperature at the early period of hydration is found to lose some of the strength gained at a later age. Such concrete is said to undergo "Retrogression of Strength". The phenomenon of retrogression of strength explains that faster hydration will result in the formation of poor quality gels with porous open structure, whereas the gel formed slowly but steadily at lower temperature are of good quality which are compact and dense in nature. This aspect can be compared to the growth of wood cells. It is common knowledge that a tree which grows faster, will yield timber *of* poor and non-durable quality, whereas a tree, which grows slowly will yield good durable timber. Similarly, concrete subjected to higher temperature in the early period of hydration will yield poor quality gels and concrete which is subjected to rather low temperature (say about 13 degree Centigrade) will yield the best quality gel, and hence good concrete.

It has been emphasized that a very young concrete should not be subjected suddenly to high temperature. Certain amount of delay period on casting the concrete is desirable. It has been found that if 49°C is reached in a period shorter than 2 to 3 hours or 99°C is reached in less than 6 to 7 hours from the time of mixing, the gain of strength beyond the first few hours is effected adversely.

Concrete subjected to steam curing exhibits a slightly higher drying shrinkage and moisture movement. Subjecting the concrete to higher temperature may also slightly effect the aggregate quality in case of some artificial aggregate. Steam curing of concrete made with rapid hardening cement will generate a much higher heat of hydration. Similarly, richer mixes may have more adverse effect than that of lean mixes.

In India', steam curing is often adopted for precast elements, specially prestressed concrete sleepers. Concrete sleepers are being introduced on the entire Indian Railway. For rapid development of strength, they use special type of cement namely IRST 40 and also subject the sleepers to steam curing.

Large numbers of bridges are being built for infrastructural development in India. There are requirements for casting of innumerable precast prestressed girders. These girders are steam cured for faster development of strength which has many other associated advantages.

A steam-curving cycle consists of

- an initial delay prior to steaming,
- a period for increasing the temperature,
- a period for retaining the temperature,
- a period for decreasing the temperature.

High Pressure Steam Curing:

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

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

The following advantages are derived from high pressure steam curing process:

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

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

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

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

When the concrete is to be subjected to high pressure steam curing, it is invariably made by admixing with 20 to 30 per cent of pozzolanic material such as crushed stone dust. In case of normal curing, the liberation of $Ca(OH)_2$ is a slow process. Therefore, when pozzolanic materials are added, the pozzolanic reactivity also will be a slow process. But in case of high pressure steam curing a good amount of $Ca(OH)_2$ will be liberated in a very short time and reaction between $Ca(OH)_2$and pozzolanic material takes place in an accelerated manner. A good amount of technical advantage is achieved by admixing the concrete with pozzolanic material. High pressure steam curing exhibits higher strength and durability particularly in the case of cement containing a proportionately higher amount of C_3S. A sample of cement containing higher proportion of C_2S is not benefited to the same extent, as it produces lower amount of $Ca(OH)_2$

It is also observed that improvement in durability is more for the concrete made with higher water/cement ratio, than for the concrete made with low water/cement ratio.

Owing to the combination of $Ca(OH)_2$ with siliceous material within a matter of 24 hours in the case of high steam curing, concrete becomes impervious and hence durable. The fact is that the concrete in the absence of free Calcium Hydroxide becomes dense and less permeable, and also accounts for higher chemical resistance and higher strength.

The higher rate of development of strength is attributed to the higher temperature to which a concrete is subjected. Earlier it is brought out that if the concrete is subjected to very high temperature, particularly in the early period of hydration, most of the strength gained will be lost because of the formation of poor quality gel. The above is true for steam cured concrete at atmospheric pressure. The high pressure steam cured concrete does not exhibit retrogression of strength. The possible explanation is that in the case of high pressure steam curing, the quality and uniformity of pore structure formed is different. At high temperature the amorphous calcium silicates are probably converted to crystalline forms. Probably due to high pressure the frame work of the gel will become more compact and dense. This perhaps explains why the retrogression of strength does not take place in the case of high pressure steam curing.

In ordinarily cured concrete, the specific surface of the gel is estimated to be about two million sq cm per gram of cement, whereas in the case of high pressure steam cured concrete, the specific surface of gel is in the order of seventy thousand sq cm per gram. In other words, the gels are about 20 times coarser than ordinarily cured concrete. It is common knowledge that finer material shrinks more than coarser material. Therefore, ordinary concrete made up of finer gels shrinks more than high pressure steam cured concrete made up of coarser gel. In quantitative terms, the high pressure steam cured concrete undergoes shrinkage of 1 /3 to I /6 of that of concrete cured at normal temperature. When pozzolanic material is added to the mix, the shrinkage is found to be higher, but still it shrinks only about 1 /2 of the shrinkage of normally cured concrete.

Due to the absence of free calcium hydroxide no efflorescence is seen in case of high pressure steam cured concrete. Due to the formation of coarser gel, the bond strength of concrete to the reinforcement is reduced by about 30 per cent to 50 per cent when compared with ordinary moist-cured concrete. High pressure steam cured concrete is rather brittle and whitish in colour. On the whole, high pressure steam curing produces good quality dense and durable concrete:

The concrete products as moulded with only a couple of hours delay period is subjected to maximum temperature over a period of 3 to 5 hours. This is followed by about 5 to 8 hours at this temperature. Pressure and temperature is realeased in about one hour. The detail steaming cycle depends on the plant, quality of material thickness of member etc. The length of delay period before subjecting to high pressure steam curing does not materially affect the quality of high pressure steam cured concrete.

Curing by Infra-red Radiation:

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

Electrical Curing:

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

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

Miscellaneous Methods of Curing:

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

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

Finishing

Finishing operation is the last operation in making concrete. Finishing in real sence does not apply to all concrete operations. For a beam concreting, finishing may not be applicable, whereas for the concrete road pavement, airfield pavement or for the flooring of a domestic building, careful finishing is of great importance. Concrete is often dubbed as a drab material, incapable of offering pleasant architectural appearance and finish. This shortcoming of concrete is being rectified and concretes these days are made to exhibit pleasant surface finishes. Particularly, many types of prefabricated concrete panels used as floor slab or wall unit are made in such a way as to give very attractive architectural affect. Even concrete claddings are made to give attractive look. In recent years there has been a growing tendency to develop and use various surface treatments which permit concrete structures to proudly proclaim its nature instead of covering itself with an expensive veneer. The property of concrete to reproduce form markings such as board mark finishes, use of linings or special types of formworks, special techniques for

the application of applied finishes have been encouraged. Surface finishes may be grouped as under:
(a) Formwork Finishes
(b) Surface Treatment
(c) Applied Finishes.

Mass Concrete

Mass concrete is a concrete having considerable dimensions that may get affected by thermal behaviour of concrete. Concrete dam is one such example of mass concrete. In the design of dam, strength of concrete is of less importance. The primary considerations are given to the aspect of how to reduce the heat of hydration, or if certain amount of heat is generated, how to absorb such heat so that the heat inside the body of concrete is minimised so that it does not cause any detrimental effect by way of cracks in concrete. Now days, there are many structural elements which are of sizeable dimensions, such as bridge piers, deep beams, massive columns, thick foundation concrete etc. The pouring of concrete in such massive sections need understanding of thermal behaviour mainly with respect to heat of hydration of concrete.
Fitz Gibbon from his research work has shown that temperature deference of more than 20°C between surface and interior causes cracks, assuming the coefficient of thermal expansion of concrete as 10 x 10–6 per °C. A deference of 20°C, the differential strain would come to 200 x 10–6. This amount of strain is considered as a realistic tensile strain at cracking. Aitcin and Raid cites a case where a 1.1 m square column made of reinforced concrete with ASTM type I cement content of 500 kg/m3 and a silica fume content of 30 kg/m3, showed a rise in temperature of 45°C above the ambient temperature, after 30 hours of placing.9.15 Therefore, there is a need for

controlling the heat of hydration in concrete and also not allowing the surface of the concrete to cool rapidly. If the surface is insulated, the difference in temperature between interior and exterior is reduced which improves the cracking behaviour. The retention of the formwork and its insulating properties may be made use of to reduce the difference in temperatures between interior and surface,. In reinforced mass concrete structures also cracking will develop, if the difference in temperature between the interior and the exterior is large. However, appropriate detailing of the reinforcement could be made to control the width and spacing of cracks. Fitz Gibbon estimated that the temperature rise under adiabatic condition is 12°C per 100 kg of cement per cubic metre of concrete, regardless of the type of cement used, for cement contents between 300 to 600 kg/m3. The above fact shows the importance of using blended cement in mass concrete and use of high volume fly ash in concrete constructions for crack free durable concrete.

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