Contents

Concrete Pump and Placing Boom at Work in a Major Construction Site.

6
CHAPTER

- Workability
- Segregation
- Bleeding
- Setting Time of Concrete
- Process of Manufacture of Concrete
- Choosing the Correct Pump
- General Points on Using Vibrators
- Further Instructions on use of Vibrators
- Curing of Concrete
- Finishing

Fresh Concrete

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state. It is worthwhile looking back at what we have discussed in Chapters I and III regarding quantity of water before we discuss its role in fresh concrete in this chapter.

In Chapter I, we have discussed the role of water and the quantity of water required for chemical combination with cement and to occupy the gel pores. We have seen that the theoretical water/cement ratio required for these two purposes is about 0.38. Use of water/cement ratio more than this, will result in capillary cavities; and less than this, will result in incomplete hydration and also lack of space in the system for the development of gel.

In Chapter III, we have discussed that while making mortar for concrete, the quantity of water used will get altered at site either due to the presence of free surface moisture in the aggregates or due to the absorption characteristics of dry and *porous aggregates. The water/cement ratio to be actually adopted at site is required to be adjusted keeping the above in mind.*

In this chapter one more aspect for deciding the water/cement ratio will be introduced i.e., the water/cement ratio required from the point of view of workability of concrete.

Workability

A theoretical water/cement ratio calculated from the considerations discussed above is not going to give an ideal situation for maximum strength. Hundred per cent compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose demaging effect on strength and durability is equally or more predominant than the presence of capillary cavities.

Degree of workability

To enable the concrete to be fully compacted with given efforts, normally a higher water/cement ratio than that calculated by theoretical considerations may be required. That is to say the function of water is also to lubricate the concrete so that the concrete can be compacted with specified effort forthcoming at the site of work. The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance.

The quality of concrete satisfying the above requirements is termed as workable concrete. The word "workability" or workable concrete signifies much wider and deeper meaning than the other terminology "consistency" often used loosely for workability. Consistency is a general term to indicate the degree of fluidity or the degree of mobility. A concrete which has high consistency and which is more mobile, need not be of right workability for a particular job. Every job requires a particular workability. A concrete which is considered workable for mass concrete foundation is not workable for concrete to be used in roof construction, or even in roof construction, concrete considered workable when vibrator is used, is not workable when concrete is to be compacted by hand. Similarly a concrete considered workable when used in thick section is not workable when required to be used in thin sections. Therefore, the word *workability assumes full significance of the type of work, thickness of section, extent of reinforcement and mode of compaction.*

For a concrete technologist, a comprehensive knowledge of workability is required to design a mix. Workability is a parameter, a mix designer is required to specify in the mix design process, with full understanding of the type of work, distance of transport, loss of slump, method of placing, and many other parameters involved. Assumption of right workability with proper understanding backed by experience will make the concreting operation economical and durable.

Many research workers tried to define the word workability. But as it signifies much wider properties and qualities of concrete, and does not project any one particular meaning, it eludes all precise definitions. Road Research laboratory, U.K., who have extensively studied the field of compaction and workability, defined workability as "the property of concrete which determines the amount of useful internal work necessary to produce full compaction." Another definition which envelopes a wider meaning is that, it is defined as the "ease with which concrete can be compacted hundred per cent having regard to mode of compaction and place of deposition." Without dwelling much on the merits and demerits of various definitions of workability, having explained the importance and full meaning of the term workability, we shall see the factors affecting workability.

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

(a) Water Content: *Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. 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 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 is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates will give higher workability. The above, of course will be true within certain limits.*

(d) Shape of Aggregates: *The shape of aggregates influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. 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 the 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 import factor which affects the workability is the use of admixtures. In Chapter 5, it is amply described that the plasticizers and superplasticizers greatly improve the workability many folds. It is to be noted that initial slump of concrete mix or what is called the slump of reference mix should be about 2 to 3 cm to enhance the slump many fold at a minimum doze. One should manupulate other factors to obtain initial slump of 2 to 3 cm in the reference mix. Without initial slump of 2 – 3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.*

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

Measurement of Workability

It is discussed earlier that workability of concrete is a complex property. Just as it eludes all precise definition, it also eludes precise measurements. Numerous attempts have been made by many research workers to quantitatively measure this important and vital property of concrete. But none of these methods are satisfactory for precisely measuring or expressing this property to bring out its full meaning. Some of the tests, measure the parameters very close to workability and provide useful information. The following tests are commonly employed to measure workability.

(*a*) *Slump Test* (*b*) *Compacting Factor Test*

(*c*) *Flow Test* (*d*) *Kelly Ball Test*

(*e*) *Vee Bee Consistometer Test.*

Slump Test

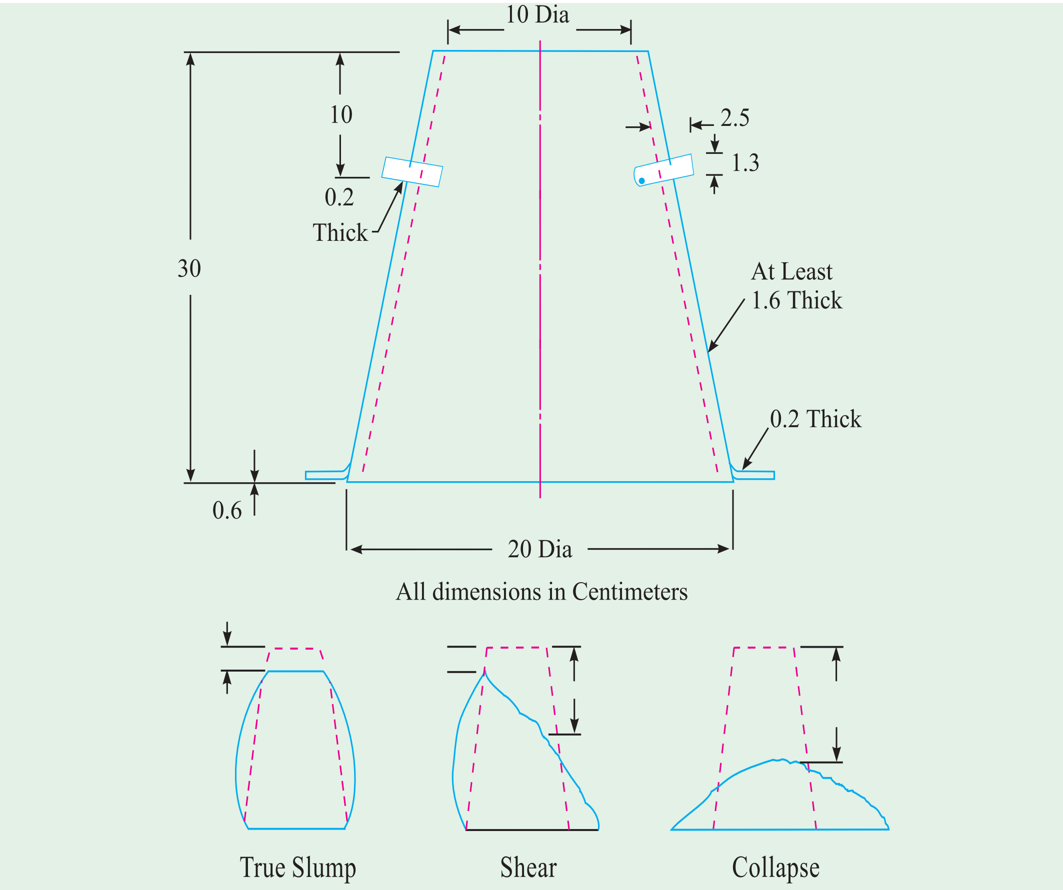
Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. However, it is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch. Repeated batches of the same mix, brought to the same slump, will have the same water content and water cement ratio, provided the weights of aggregate, cement and admixtures are uniform and aggregate grading is within acceptable limits. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. Quality of concrete can also be further assessed by giving a few tappings or blows by tamping rod to the base plate. The deformation shows the characteristics of concrete with respect to tendency for segregation.

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

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

The thickness of the metallic sheet for the mould should not be thinner than 1.6 mm. Sometimes the mould is provided with suitable guides for lifting vertically up. For tamping the concrete, a steel tamping rod 16 mm dia, 0.6 meter along with bullet end is used. Fig. 6.1, shows the details of the slump cone appartus. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal, rigid and non-absorbant surface The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking

Slump Test Apparatus



care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as SLUMP of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete. ASTM measure the centre of the slumped concrete as the difference in height. ASTM also specifies 3 layers.

The pattern of slump is shown in Fig. 6.2. It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slamp. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation.

It is seen that the slump test gives fairly good consistent results for a plastic-mix. This test is not sensitive for a stiff-mix. In case of dry-mix, no variation can be detected between mixes of different workability. In the case of rich mixes, the value is often satisfactory, their slump being sensitive to variations in workability. IS 456 of 2000 suggests that in the "very low" category of workability where strict control is necessary, for example, pavement quality concrete, (PQC) measurement of workability by determination of compacting factor will be more appropriate than slump and a value of 0.75 to 0.80 compacting factor is suggested.

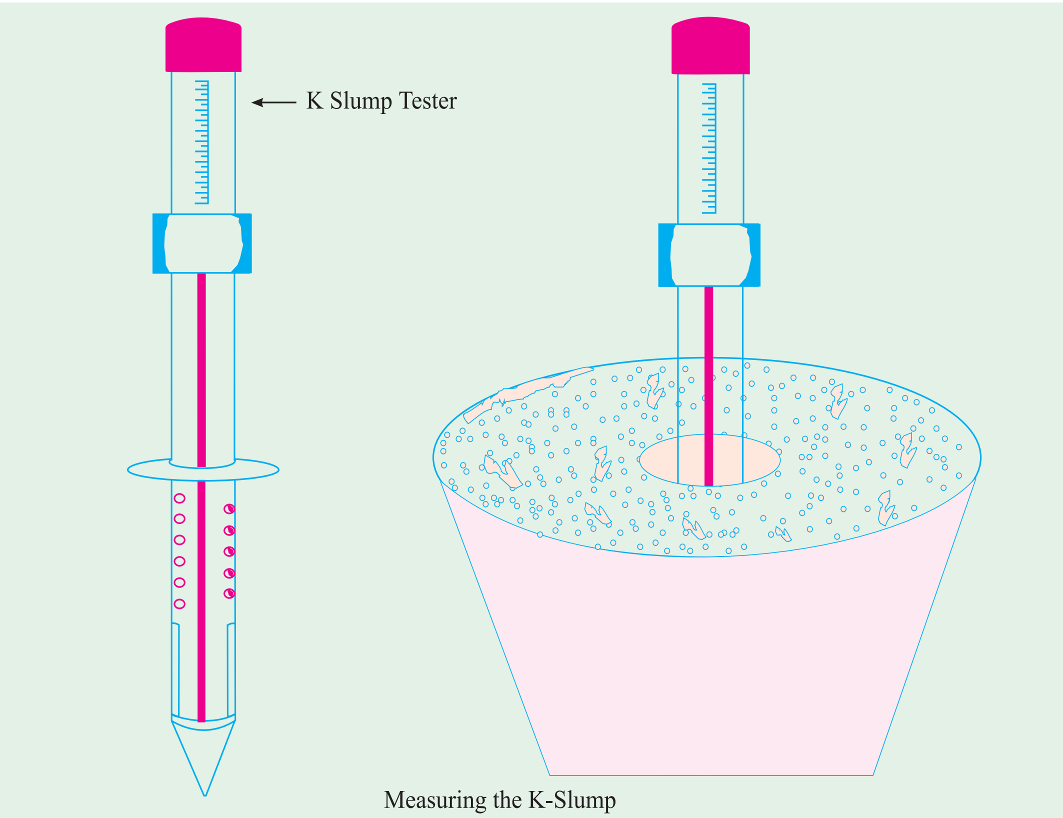
The above IS also suggests that in the "very high" category of workability, measurement of workability by determination of "flow" by flow test will be more appropriate. However, in a lean-mix with a tendency of harshness a true slump can easily change to shear slump. In such case, the tests should be repeated.

Despite many limitations, the slump test is very useful on site to check day-to-day or hour-to-hour variation in the quality of mix. An increase in slump, may mean for instance that the moisture content of the aggregate has suddenly increased or there has been sudden change in the grading of aggregate. The slump test gives warning to correct the causes for change of slump value. The simplicity of this test is yet another reason, why this test is still popular in spite of the fact that many other workability tests are in vogue. Table 6.1 shows the nominal slump value for different degrees of workability.

The Bureau of Indian standards, in the past, generally adopted compacting factor test values for denoting workability. Even in the IS 10262 of 1982 dealing with Recommended Guide Line for Concrete Mix Design, adopted compacting factor for denoting workability. But now in the revision of IS 456 of 2000 the code has reverted back to slump value to denote the workability rather than compacting factor. It shows that slump test has more practical utility than the other tests for workability.

K-Slump Tester

Very recently a new appartus called "K-Slump Tester" has been devised.[6.1] *It can be used to measure the slump directly in one minute after the tester is inserted in the fresh concrete to the level of the floater disc. This tester can also be used to measure the relative workability.*



Measuring the K-Slump

The appartus comprises of the following four principal parts:-

1. *A chrome plated steel tube with external and internal diameters of 1.9 and 1.6 cm respectively. The tube is 25 cm long and its lower part is used to make the test. The length of this part is 15.5 cm which includes the solid cone that facilitates inserting the tube into the concrete. Two types of openings are provided in this part: 4 rectangular slots 5.1 cm long and 0.8 cm wide and 22 round holes 0.64 cm in diameter; all these openings are distributed uniformly in the lower part as shown in Figure 6.3.*

K-Slump Tester

Table 6.1. Workability, Slump and Compacting Factor of Concretes with 20 mm or 40 mm Maximum Size of Aggregate

Degree of workability	*Slump mm*	*Compacting factor*		*Use for which concrete is suitable*
		Small appartus	*Large appartus*	
Very Low compacting factor is suitable	–	0.78	0.80	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25–75	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete 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	50–100	0.92	0.935	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration
High	100–150	0.95	0.96	For sections with congested reinforcement. Not normally suitable for vibration. For pumping and tremie placing
Very High	–	–	–	Flow table test is more suitable.

2. *A disc floater 6 cm in diameter and 0.24 cm in thickness which divides the tube into two parts: the upper part serves as a handle and the lower one is for testing as already mentioned. The disc serves also to prevent the tester from sinking into the concrete beyond the preselected level.*
3. *A hollow plastic rod 1.3 cm in diameter and 25 cm long which contains a graduated scale in centimeters. This rod can move freely inside the tube and can be used to measure the height of mortar that flows into the tube and stays there. The rod is plugged at each end with a plastic cap to prevent concrete or any other material from seeping inside.*
4. *An aluminium cap 3 cm diameter and 2.25 cm long which has a little hole and a screw that can be used to set and adjust the reference zero of the apparatus. There is also in the upper part of the tube, a small pin which is used to support the measuring rod at the beginning of the test. The total weight of the appartus is 226 g.*

The following procedure is used:

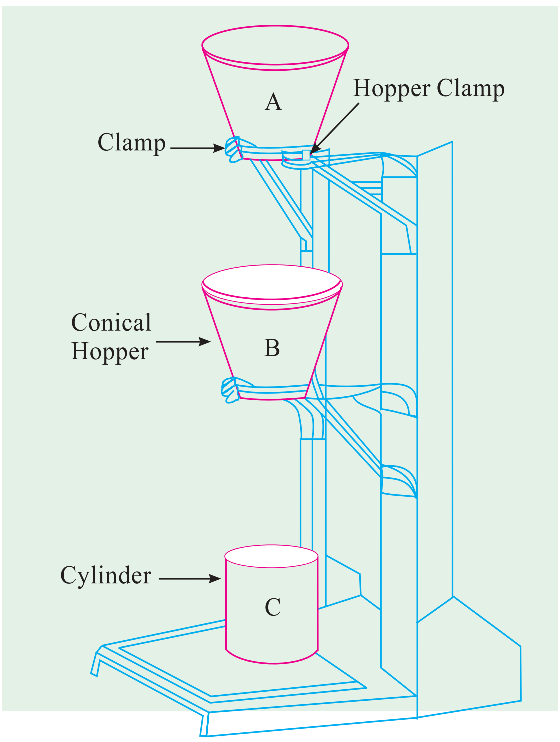
(a) *Wet the tester with water and shake off the excess.*

(b) *Raise the measuring rod, tilt slightly and let it rest on the pin located inside the tester.*

(c) *Insert the tester on the levelled surface of concrete vertically down until the disc floater rests at the surface of the concrete. Do not rotate while inserting or removing the tester.*

(d) *After 60 seconds, lower the measuring rod slowly until it rests on the surface of the concrete that has entered the tube and read the K-Slump directly on the scale of the measuring rod.*

(e) *Raise the measuring rod again and let it rest on its pin.*



Compacting Factor Apparatus

(f) Remove the tester from the concrete vertically up and again lower the measuring rod slowly till it touches the surface of the concrete retained in the tube and read workability (W) directly on the scale of the measuring rod.

Remarks

In the concrete industry, the slump test is still the most widely used test to control the consistency of concrete mixtures, even though there are some questions about its significance and its effectiveness. Many agree that the test is awkward and is not in keeping with the strides that the industry has made since 1913 when the slump cone was first introduced. Several apparatus have been proposed to replace or supplement the slump cone, but in general they have proved to be rich in theory and poor in practice. Their use is still limited mainly to research work in laboratories.

The K-slump apparatus is very simple, practical, and economical to use, both in the field and the laboratory. It has proven, with over 450 tests, that it has a good correlation with the slump cone.

The K-slump tester can be used to measure slump in one minute in cylinders, pails, buckets, wheel-barrows, slabs or any other desired location where the fresh concrete is placed. A workability index can be determined by the tester.

Compacting Factor Test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test. The diagram of the apparatus is shown in Figure 6.4. The essential dimensions of the hoppers and mould and the distance between them are shown in Table 6.2.

The compacting factor test has been developed at the Road Research Laboratory U.K. and it is claimed that it is one of the most efficient tests for measuring the workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The degree of compaction, called the compacting factor is measured by the density ratio *i.e.*, the ratio of the density actually achieved in the test to density of same concrete fully compacted.

Table 6.2. Essential Dimension of the Compacting Factor Appartus for use with Aggregate not exceeding 40 mm Nominal Max. Size

Upper Hopper, A	Dimension cm
Top internal diameter	25.4
Bottom internal diameter	12.7
Internal height	27.9
Lower hopper, B	
Top internal diameter	22.9
Bottom internal diameter	12.7
Internal height	22.9

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

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

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

The weight of fully compacted concrete can also be calculated by knowing the proportion of materials, their respective specific gravities, and the volume of the cylinder. It is seen from experience, that it makes very little difference in compacting factor value, whether the weight of fully compacted concrete is calculated theoretically or found out actually after 100 per cent compaction.

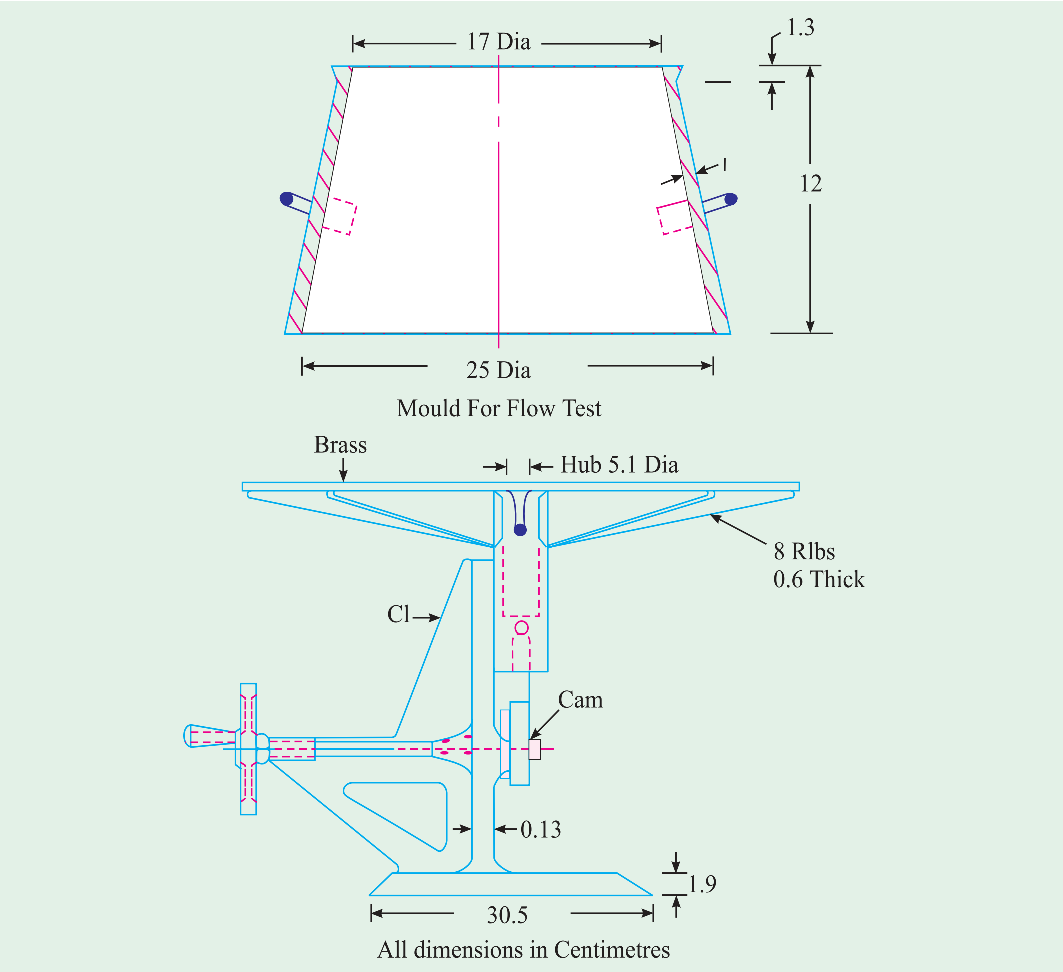
It can be realised that the compacting factor test measures the inherent characteristics of the concrete which relates very close to the workability requirements of concrete and as such it is one of the good tests to depict the workability of concrete.

Flow Test

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

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

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



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

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

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

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

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 1881 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 Fig. 6.6. (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. 6.6 (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. 6.6. (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± 1 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.

Accessory Apparatus

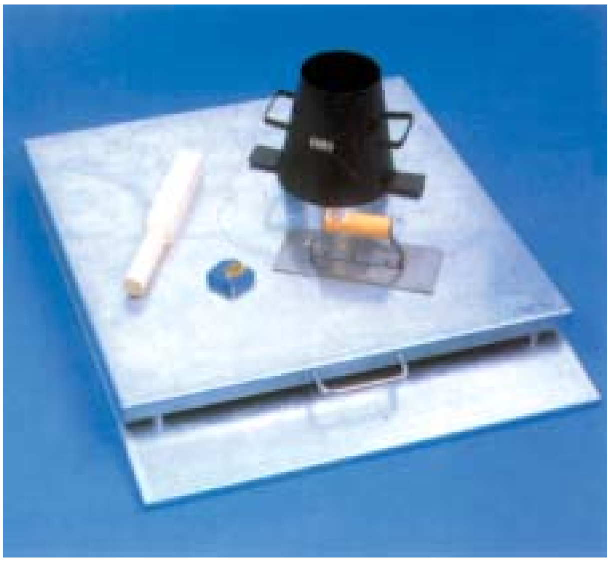
Mould: The mould is made of metal readily not attacked by cement paste or liable to rust and of minimum thickness 1.5 mm. The interior of the mould is smooth and free from projections, such as protruding rivets, and is free from dents. The mould shall be in the form of a hollow frustum of a cone having the internal dimensions as shown in Fig. 6.7. The base and the top is open and parallel to each other and at right angles to the axis of the cone. The mould is provided with two metal foot pieces at the bottom and two handles above them.

Tamping Bar: *The tamping bar is made of a suitable hardwood and having dimensions as shown in Fig. 6.8.*

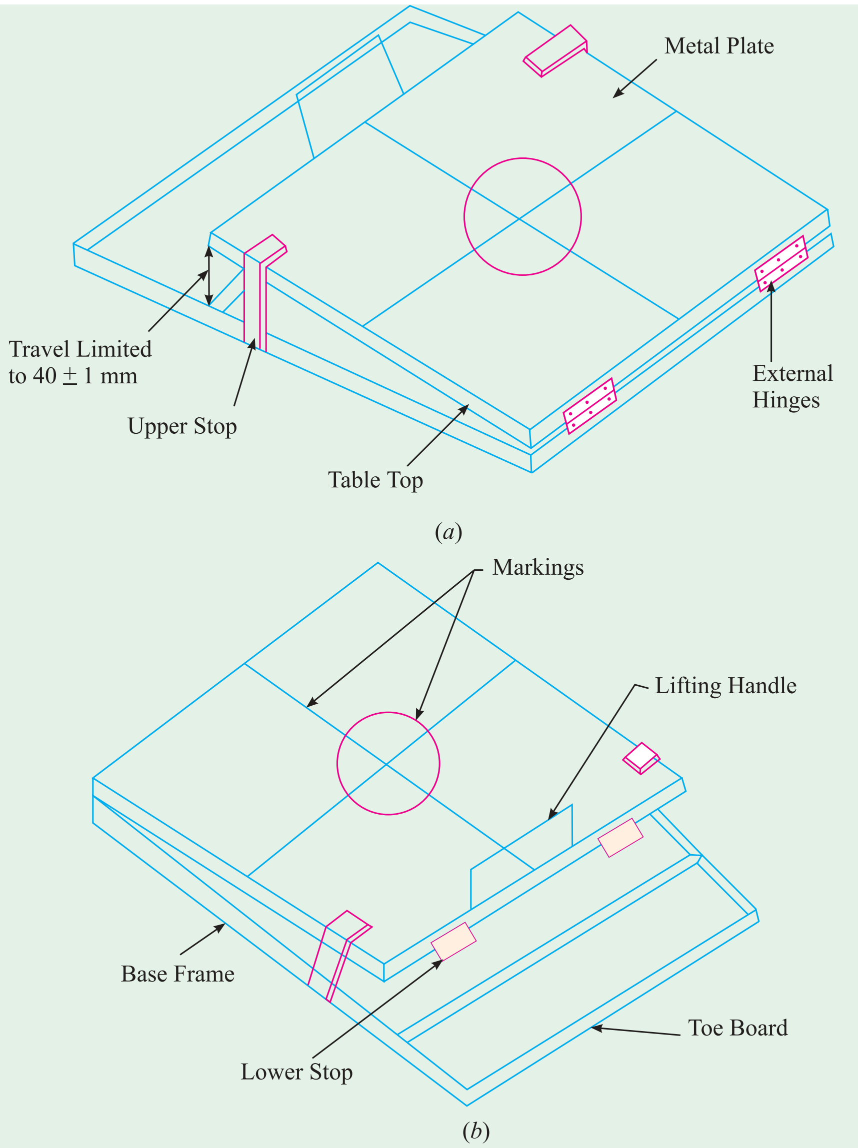
Sampling: *The sample of freshly mixed concrete is obtained.*

Procedure: *The table is made level and properly supported. Before commencing the test, the table-top and inner surface of the mould is wiped with a damp cloth. The slump cone is placed centrally on the table. The slump cone is filled with concrete in two equal layers, each layer tamped lightly 10 times with the wooden tamping bar. After filling the mould, the concrete is struck off flush with the upper edge of the slump cone and the free area of the table-top cleaned off.*

Half a minute after striking off the concrete, the cone is slowly raised vertically by the handles. After this, the table-top raised by the handle and allowed to fall 15 times in 15 seconds. The concrete spreads itself out. The diameter of the concrete spread shall



Flow Table Apparatus

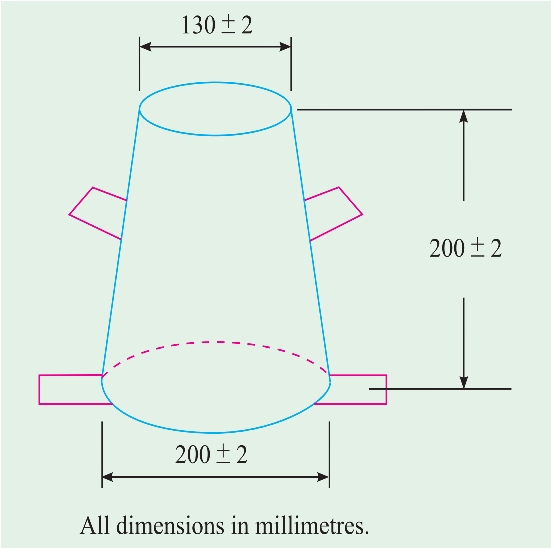


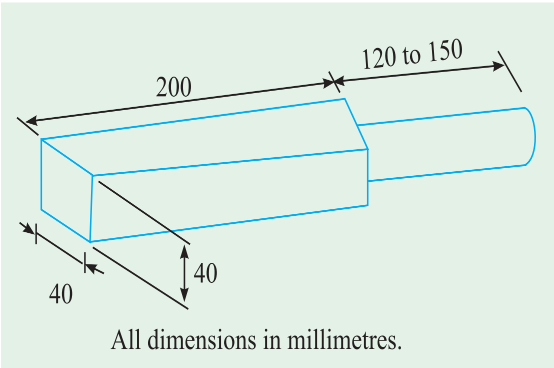
All dimensions in Millietres

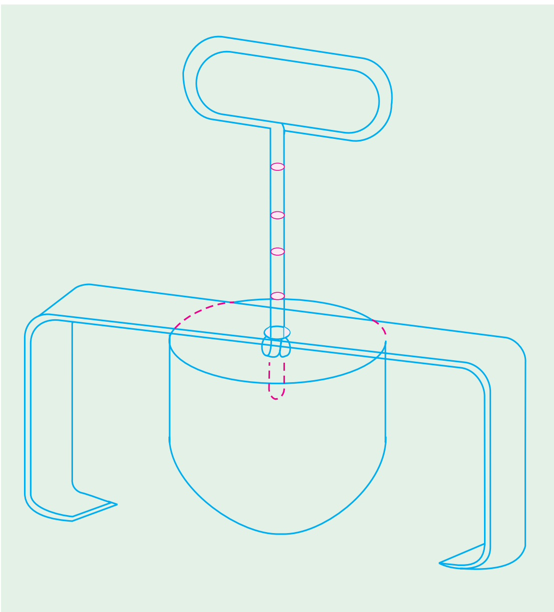
then be measured in two directions, parallel to the table edges. The arithmetic mean of the two diameters shall be the measurement of flow in millimeters.

Kelly Ball Test

This is a simple field test consisting of the measurement of the indentation made by 15 cm diameter metal hemisphere weighing 13.6 kg. when freely placed on fresh concrete. The test has been devised by Kelly and hence known as Kelly Ball Test. This has not been covered by Indian Standards Specification. The advantages of this test is that it can be performed on the concrete placed in site and it is claimed that this test can be performed faster with a greater precision than slump test. The disadvantages are that it requires a large sample of concrete and it cannot be used when the concrete is placed in thin section. The minimum







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

The surface of the concrete is struck off level, avoiding excess working, the ball is lowered gradually on the surface of the concrete. The depth of penetration is read immediately on the stem to the nearest 6 mm. The test can be performed in about 15 seconds and it gives much more consistent results than Slump Test. Fig. 6.9. shows the Kelly Ball apparatus.

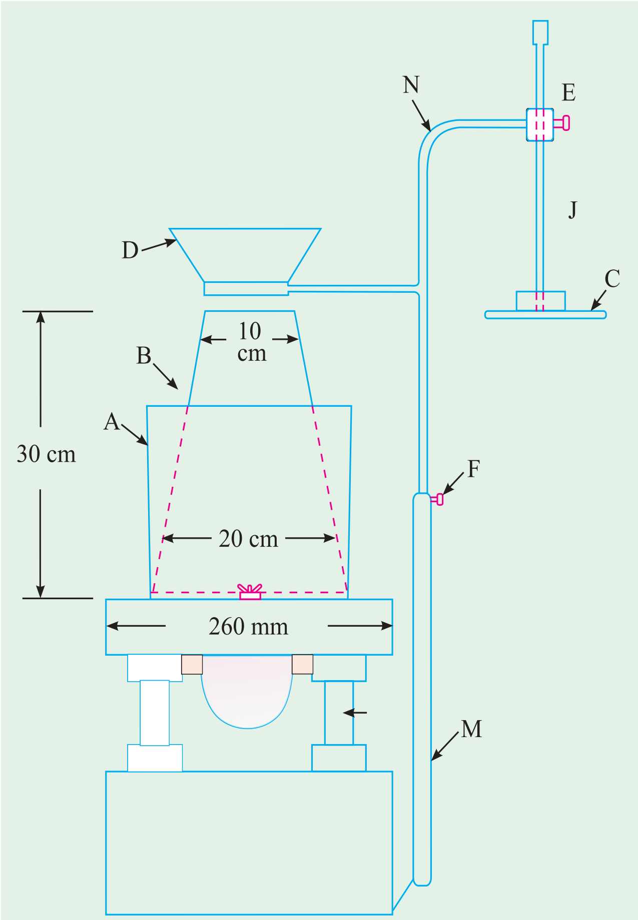
Vee Bee Consistometer Test

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. The apparatus is shown in Figure. 6.10.

Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer. The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot. The electrical vibrator is then switched on and simultaneously a stop watch started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test, but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. If a sample of concrete exhibits a tendency for separation of say, coarse aggregate from the rest of the ingredients, then, that sample is said to be showing the tendency for segregation. Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.



There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart. Segregation may be of three types — firstly, the coarse aggregate separating out or settling down from the rest of the matrix, secondly, the paste or matrix separating away from coarse aggregate and thirdly, water separating out from the rest of the material being a material of lowest specific gravity.

Vee-Bee Consistometer

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

The conditions favourable for segregation are, as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation. When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete shows a tendency for segregation. Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete.

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

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

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

From the foregoing discussion, it can be gathered that the tendency for segregation can be remedied by correctly proportioning the mix, by proper handling, transporting, placing, compacting and finishing. At any stage, if segregation is observed, remixing for a short time would make the concrete again homogeneous. As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air-entraining agent appreciably reduces segregation.

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

Bleeding

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

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

In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season. Owing to the fact that the top surface has a higher content of water and is also devoid of aggregate matter; it also develops higher shrinkage cracks. If laitance is formed on a particular lift, a plane of weakness would form and the bond with the next lift would be poor. This could be avoided by removing the laitance fully before the next lift is poured.

Example of external bleeding

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

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

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

Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse. It has been already discussed that the use of air-entraining agent is very effective in reducing the bleeding. It is also reported that the bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less susceptible to bleeding than lean mixes.

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

Bleeding presents a very serious problem when Slip Form Paver is used for construction of concrete pavements. If two much of bleeding water accumulates on the surface of pavement slab, the bleeding water flows out over the unsupported sides which causes collapsing of sides. Bleeding becomes a major consideration in such situations.

In the pavement construction finishing is done by texturing or brooming. Bleeding water delays the texturing and application of curing compounds.

Method of Test for Bleeding of Concrete

This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

A cylindrical container of approximately 0.01 m^3 capacity, having an inside diameter of 250 mm and inside height of 280 mm is used. A tamping bar similar to the one used for slump test is used. A pepette for drawing off free water from the surface, a graduated jar of 100 cm^3 capacity is required for test.

A sample of freshly mixed concrete is obtained. The concrete is filled in 50 mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giving strokes, and the top surface is made smooth by trowelling.

The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m^3 of concrete quantity of water in the cylindrical container is also calculated.

The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C. it is covered with a lid. Water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 minutes and at 30 minutes interval subsequently till bleeding ceases. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding water percentage} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in the sample of concrete}} \times 100$$

Setting Time of Concrete

We have discussed about the setting time of cement in Chapter 2. Setting time of cement is found out by a standard vicat apparatus in laboratory conditions. Setting time, both initial and final indicate the quality of cement.

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which the concrete is made. The setting time of concrete depends upon the w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizers–in particular retarding plasticizer. The setting parameter of concrete is more of practical significance for site engineers than setting time of cement. When retarding plasticizers are used, the increase in setting time, the duration upto which concrete remains in plastic condition is of special interest.

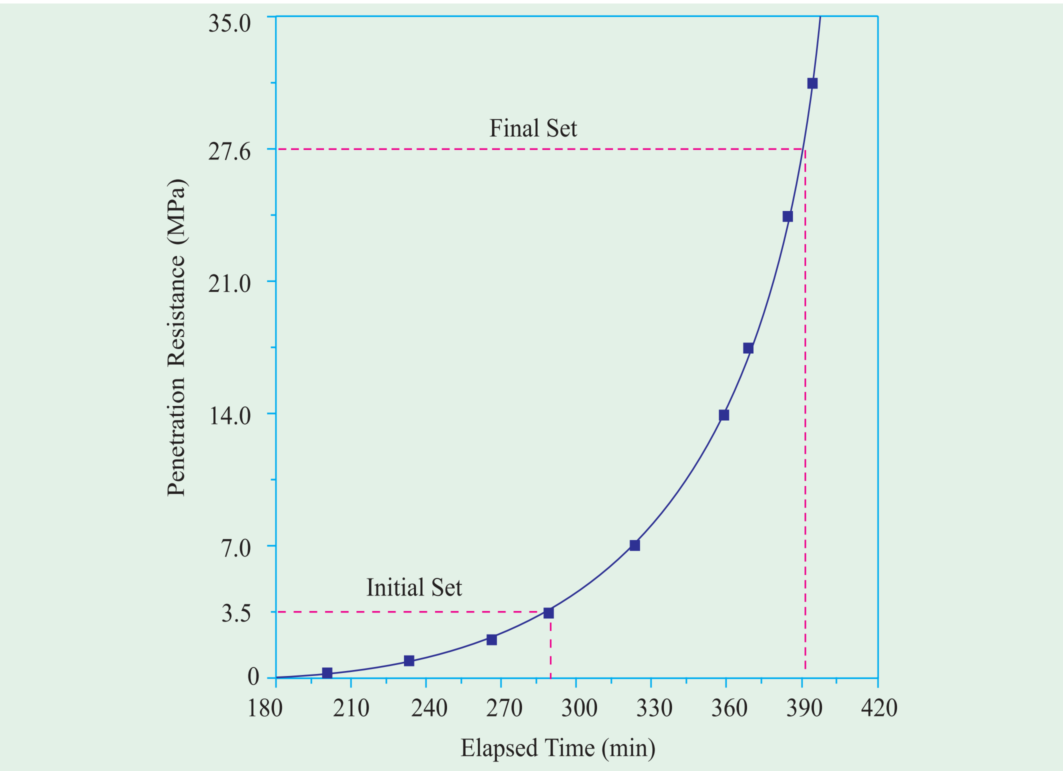
The setting time of concrete is found by pentrometer test. This method of test is covered by IS 8142 of 1976 and ASTM C – 403. The procedure given below may also be applied to prepared mortar and grouts.

The apparatus consist of a container which should have minimum lateral dimension of 150 mm and minimum depth of 150 mm.

There are six penetration needles with bearing areas of 645, 323, 161, 65, 32 and 16 mm^2. Each needle stem is scribed circumferentially at a distance of 25 mm from the bearing area.

A device is provided to measure the force required to cause penetration of the needle.

The test procedure involves the collection of representative sample of concrete in sufficient quantity and sieve it through 4.75 mm sieve and the resulting mortar is filled in the container. Compact the mortar by rodding, tapping, rocking or by vibrating. Level the surface and keep it covered to prevent the loss of moisture. Remove bleeding water, if any, by means of pipette. Insert a needle of appropriate size, depending upon the degree of setting of the mortar in the following manner.



Bring the bearing surface of needle in contact with the mortar surface. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5 mm, as indicated by the scribe mark. The time taken to penetrate 25 mm depth could be about 10 seconds. Record the force required to produce 25 mm penetration and the time of inserting from the time water is added to cement. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance. For the subsequent penetration avoid the area where the mortar has *been disturbed. The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25 mm away from the wall of container.*

Plot a graph of penetration resistance as ordinate and elapsed time as abscissa. Not less than six penetration resistance determination is made. Continue the tests until one penetration resistance of at least 27.6 MPa is reached. Connect the various point by a smooth curve.

Needle with different bearing area

From penetration resistance equal to 3.5 MPa, draw a horizontal line. The point of intersection of this with the smooth curve, is read on the x-axis which gives the initial setting time. Similarly a horizontal line is drawn from the penetration resistance of 27.6 MPa and point it cuts the smooth curve is read on the x-axis which gives the final set.

A typical graph is shown in Fig. 6.11

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.

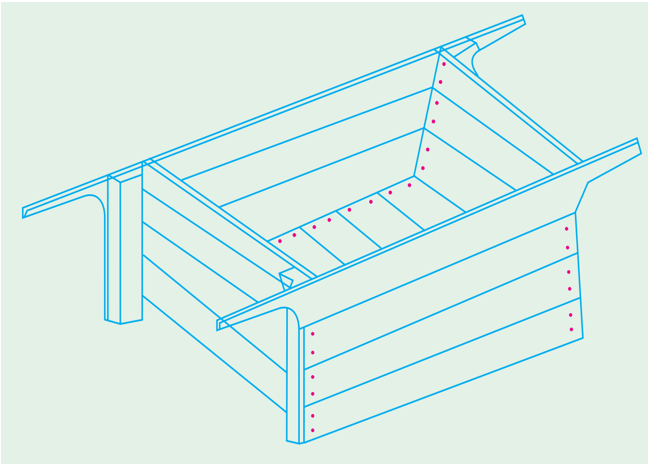
(a) Batching

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

(i) Volume batching *(ii) Weigh batching*

(i) 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 have 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. The typical sketch of a guage box is shown in Figure 6.12. The volume of the box is made equal to the volume of one bag of cement i.e., 35 litres or multiple thereof. The gauge boxes are



made comparatively deeper with narrow surface rather than shallow with wider surface to facilitate easy estimation of top level. Sometimes bottomless gauge-boxes are used. This should be avoided. Correction to the effect of bulking should be made to cater for bulking of fine aggregate, when the fine aggregate is moist and volume batching is adopted.

Gauge boxes are generally called farmas. They can be made of timber or steel plates. Often in India volume batching is adopted even for large concreting operations. In a major site it is recommended to have the following gauge boxes at site to cater for change in Mix Design or bulking of sand. The volume of each gauge box is clearly marked with paint on the external surface.

Table 6.3. Volume of Various gauge boxes

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

The batch volume for some of the commonly used mixes is shown in Table 6.4.

Table 6.4 Batch volume of materials for various mixes

	Cement kg.	Sand, litres	Coarse aggregate, litres
1 : 1 : 2 (M 200)	50	35	70
1 : 1 1/2 : 3 (M 200)	50	52.5	105
1 : 2 : 3	50	70	105
1 : 2 : 4 (M 150)	50	70	140
1 : 2 1/2 : 5	50	87.5	175
1 : 3 : 6 (M 100)	50	105	210

Water is measured either in kg. or litres as may be convenient. In this case, the two units are same, as the density of water is one kg. per litre. The quantity of water required is a product of water/cement ratio and the weight of cement; for a 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 present in the aggregate.*

The following table gives the approximate surface moisture carried by aggregates

Table 6.5. Approximate Surface moisture in aggregate–I.S. 456-2000

Aggregates	*Approximate Quantity of surface water*	
	Percent by Mass	*Litre per m^3*
(1)	*(2)*	*(3)*
Very wet sand	*7.5*	*120*
Moderately wet sand	*5.0*	*80*
Moist sand	*2.5*	*40*
Moist gravel or crushed rock	*1.25 – 2.5*	*20 – 40*

(ii) 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 the 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.*

Weigh Batcher

On large work sites, the weigh bucket type of weighing equipments are 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 operation. 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 has only to 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 transporation, 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.

Cans for measuring water

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:

(*i*) Hand mixing (*ii*)Machine mixing

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.

Laboratory tilting drum mixer

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. This type 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. Fig 6.13 illustrates diagrammatically the type of mixers.

Pan / paddle mixer

Concrete mixer with hydraulic hopper 10/7

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.

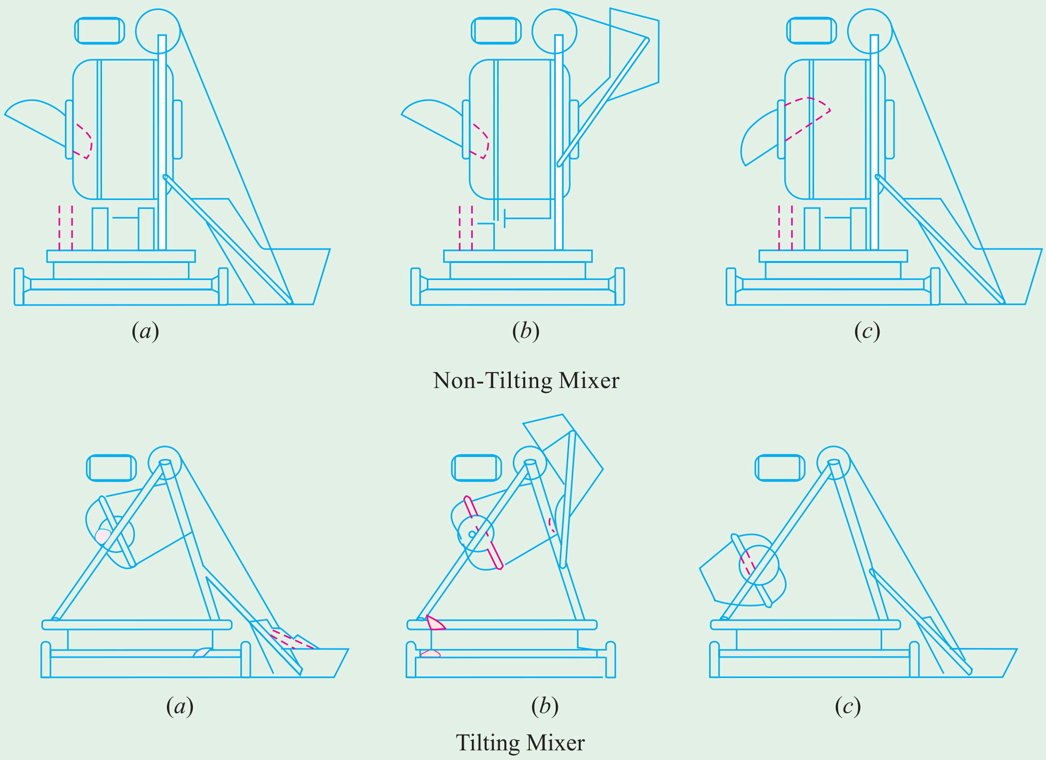
Reversible drum concrete mixer / mini batching plant

When plasticizer or superplasticizer

Concrete high-speed mixer in a batching plant.

is used, the usual procedure could be adopted except that about one litre of water is held back. Calculated quantity of plasticizer or superplasticizer 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. Plasticizer in small quantity do not get properly dispersed with cement particles. To improve the situations, the following sequence may be adopted.

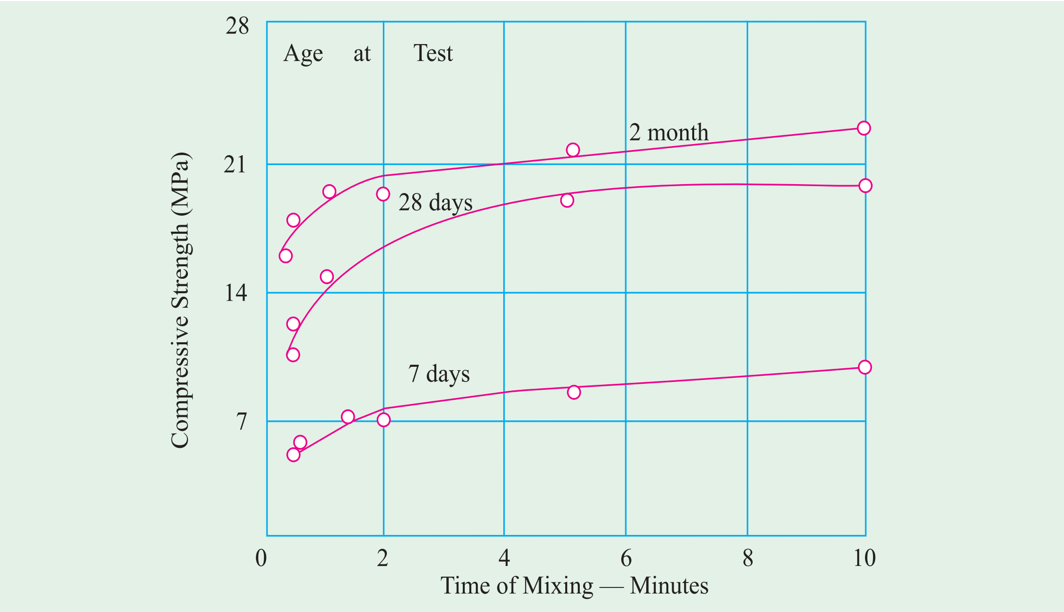


(*a*) Filling Material into Loading Skip
(*b*) Discharging Skip into Mixing Drum
(*c*) Concrete Discharged From Drum

Fig. 6.13. Illustrating Diagrammatically the Method of Operation of the Rotary and Tilting Type Concrete Mixer

Firstly, add all the water except about half a litre. Add cement and then add sand. Make an intimate mortar mix. Dilute calculated quantity of plasticizer with the remaining half a litre of water and pour it into the drum. Rotate the drum for another half a minute, so that plasticizer gets well mixed with cement mortar and then add both the fractions (20 mm and 10 mm) of coarse aggregate. This procedure is found to give better and consistent results.

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 the 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. Fig. 6.14. shows the effect of mixing time on strength of concrete.

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 1½ to 2½ 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.

Retempering of Concrete

Often long hauls are involved in the following situation-delivery of concrete from central mixing plant, in road construction, in constructing lengthy tunnels, in transportation of concrete by manual labour in hilly terrain. Loss of workability and undue stiffening of concrete may take place at the time of placing on actual work site. Engineers at site, many a time, reject the concrete partially set and unduly stiffened due to the time elapsed between mixing and placing. Mixed concrete is a costly material and it can not be wasted without any regard to cost. It is required to see whether such a stiffened concrete could be used on work without *undue harm. The process of remixing of concrete, if necessary, with addition of just the required quantity of water is known as "Retempering of Concrete". Sometimes, a small quantity of extra cement is also added while retempering. Many specifications do not permit retempering. I.S. 457 – 1957 did not permit retempering of partially hardened concrete or mortar requiring renewed mixing, with or without addition of cement, aggregate or water. However, many research workers are of the view that retempering with the addition of a small quantity of water may be permitted to obtain the desired slump provided the designed water/cement ratio is not exceeded. They caution that the production of concrete of excessive slump or adding water in excess of designed water cement ratio to compensate for slump loss resulting from delays in delivery or placing should be prohibited. It is seen from the investigations, retempering of concrete which is too wet a mix, at a delay of about one hour or so showed an increase in compressive strength of 2 to 15 per cent. Retempering at further delay resulted in loss of strength. However, this loss of strength is smaller than would be expected from the consideration of the total water/cement ratio i.e., the initial water cement ratio plus water added for retempering to bring the mix back into the initial degree of workability.*

Maintenance of Mixer

Concrete mixers are often used continuously without stopping for several hours for continuous mixing and placing. It is of utmost importance that a mixer should not stop in between concreting operation. For this reason, concrete mixer must be kept well maintained. Mixer is placed at the site on a firm and levelled platform. The drum and blades must be kept absolutely clean at the end of concreting operation. The drum must be kept in the tilting position or kept covered when not in use to prevent the collection of rain water. The skip is operated carefully and it must rest on proper cushion such as sand bags.

Transporting Concrete

Concrete can be transported by a 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*) Wheel Barrow, Hand Cart
- (*c*) Crane, Bucket and Rope way
- (*d*) Truck Mixer and Dumpers
- (*e*) Belt Conveyors
- (*f*) Chute
- (*g*) Skip and Hoist
- (*h*) Tansit Mixer
- (*i*) Pump and Pipe Line
- (*j*) Helicoptor.

Mortar Pan: *Use of mortar pan for transporation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case, concrete is carried in small quantities. While this method nullifies the segregation to some extent, particularly in thick members, it suffers from the disadvantage that this method exposes greater surface area of concrete for drying conditions. This results in*

Tough Rider for transporting concrete.


Truck mixer and dumper for transporting stiff concrete

greater loss of water, particularly, in hot weather concreting and under conditions of low humidity. It is to be noted that the mortar pans must be wetted to start with and it must be kept clean during the entire operation of concreting. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much 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 a 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.

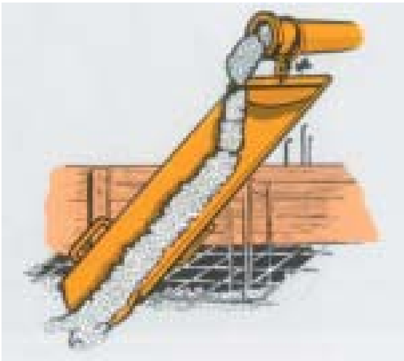
Truck Mixer and Dumpers: *For large concrete works particularly for concrete to be placed at ground level, trucks and dumpers or ordinary open steel-body tipping lorries can be used. As they can travel to any part of the work, they have much advantage over the jubilee wagons, which require rail tracks. 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. (Electrical conduits or switch boards etc.,).

Skip and Hoist: *This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging and human ladder for transporting*

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

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

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

Transit Mixer

Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMC). 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 is less vulnerable in case of delay. The truck mixer the speed of rotating of drum is between 4–16 revolution 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 $1\frac{1}{2}$ 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.

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.

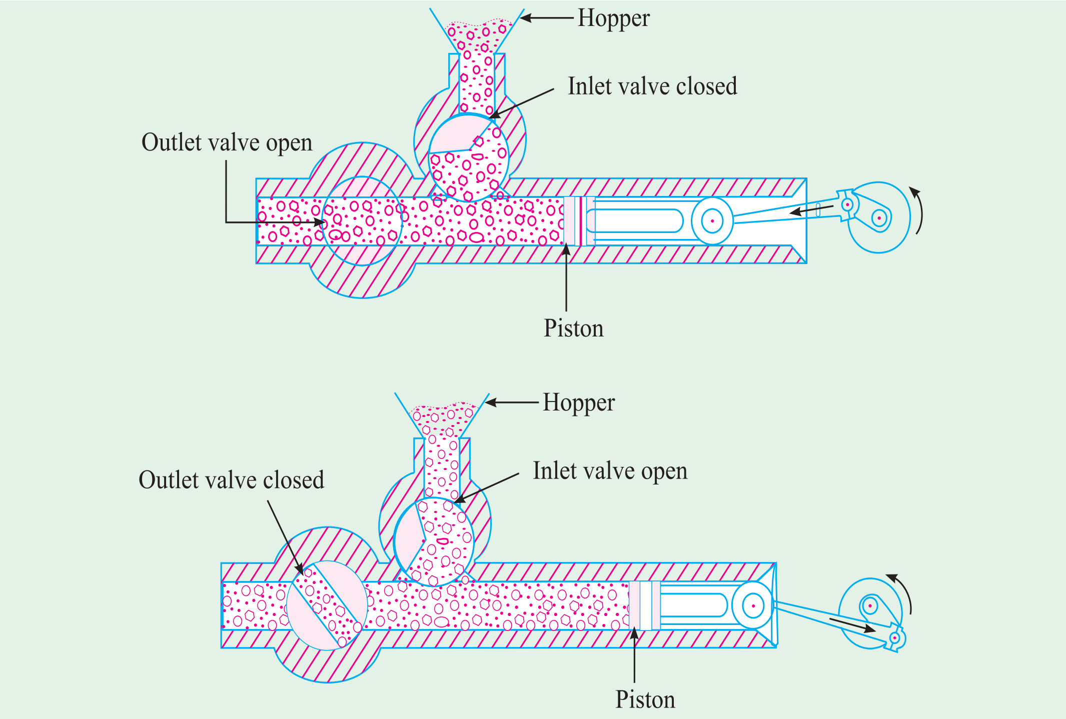
Pumping arrangements

As per estimate made by CM Doordi, the cost of transportation of concrete by transit mixer varies between Rs 160 to 180 per cubic metre.[6.2]

Pumps and Pipeline

Pumping of concrete is universally accepted as one of the main methods of concrete transportation and placing. Adoption of pumping is increasing throughout the world as pumps become more reliable and also the concrete mixes that enable the concrete to be pumped are also better understood.

Development of Concrete Pump: *The first patent for a concrete pump was taken in USA in the year 1913* [6.3]*. By about 1930 several countries developed and manufactured concrete pump with sliding plate valves. By about 1950s and 1960s concrete pumping became widely used method in Germany. Forty per cent of their concrete was placed by pumping. The keen rivalry between the leading German manufacturers, namely, Schwing, Putzmeister and Elba, has boosted the development of concrete pump and in particular the valve design which is*



the most important part of the whole system.

Concrete Pumps: *The modern concrete pump is a sophisticated, reliable and robust machine. In the past a simple two-stroke mechanical pump consisted of a receiving hopper, an inlet and an outlet valve, a piston and a cylinder. The pump was powered by a diesel engine. The*

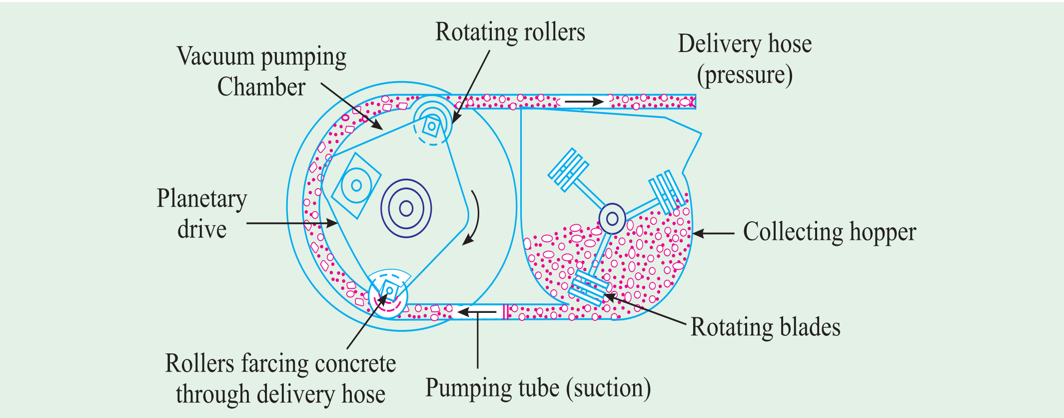
Pump and pipeline

pumping action starts with the suction stroke drawing concrete into the cylinder as the piston moves backwards. During this operation the outlet value is closed. On the forward stroke, the inlet valve closes and the outlet valve opens to allow concrete to be pushed into the delivery pipe. Fig. 6.15 illustrates the principle.

The modern concrete pump still operates on the same principles but with lot of improvements and refinements in the whole operations. During 1963, squeeze type pump was developed in U.S.A. In this concrete placed in a collecting hopper is fed by rotating blades into a flexible pipe connected to the pumping chamber, which is under a vacuum of about 600 mm of mercury. The vacuum ensures that, except when being squeezed by roller, the pipe shape remains cylindrical and thus permits a continuous flow of concrete. Two rotating rollers progressively squeeze the flexible pipes and thus move the concrete into the delivery pipe. Fig. 6.16. shows the action of squeeze pump.

The hydraulic piston pump is the most widely used modern pump. Specification differ but concept of working of modern pump is the same as it was for original mechanically driven pumps. A pump consists of three parts, a concrete receiving happer, a valve system and a power transmission system.

There are three main types of concrete pump. They are mobile, trailor or static and screed or mortar pump.



Types of valve: *The most important part of any concrete pump is the valve system. The main types of valve are peristaltic or squeeze type valves, sliding gate or rotating value, flapper valves, and hollow transfer tube valves.*

Hollow transfer tube valves are most commonly used type of valve. Another type which is used extensively is the Rock Valve. The S valve used by Putzmeister is another example of a transfer tube value.

Pipelines and couplings: *It is not enough to have an efficient pump. It is equally important to have correct diameter of pipeline with adequate wall thickness for a given operating pressure and well designed coupling system for trouble free operation. A poor pipeline can easily cause blockages arising from leakage of grout. Pushing of abrasive material at high pressure, through pipeline inevitably creates a great deal of wear. Continuous handling, frequent securing and releasing of couplings creates wear at joints. All these must be maintained well for trouble free function and safety.*

It is important to choose the correct diameter and wall thickness of the pipeline to match the pump and required placing rate. Generally almost all pumped concrete is conveyed through 125 mm pipeline. There are exceptions. For long, horizontal distance involving high pumping pressures, a large diameter pipe would be more suitable on account of less resistance to flow. For pumping concrete to heights, on account of the fact that gravity and the weight of concrete in the line, a smallest possible diameter of pipelines should be used.

As a guide, a pump with an output of 30 m^3/h and with not more than 200 m of pipeline one may suggest 100 mm diameter, but for length in excess of 500 meter, a 150 mm diameter could be considered.

Diameter of pipeline has also bearing on the size of aggregate. General rule is that the pipe diameter should be between 3 to 4 times the largest size of aggregate. For example if maximum size of aggregate in concrete is 40 mm, the diameter of pipe could be between 120 mm to 160 mm. But use of 125 mm pipe can be considered suitable.

The individual pipe sections with lengths of 1m, 2m or 3 m are connected by means of various types of quick-locking couplings. For change in pipe line directions bends of different degrees (90 deg., 60 deg., 45 deg., 30 deg. and 15 deg.) are available. The bends have a radius of 1 m. But bends with radius of r = 250 mm are used in placing booms.

Laying the Pipeline: *A carefully laid pipeline is the prerequisite for trouble free pumping operation. Time, money and trouble are saved at sites if the installation of concrete pump and the laying of pipelines are thoroughly planned and carried out with care. Leaky pipes and coupling points often results in plugs and impede the pushing of concrete on account of escape of air or water. Pipelines must be well anchored when bends are introduced.*

Particular care must be taken when laying vertical line. It is difficult to dismantle individual pipe. Therefore, install only such pipes which are in good condition. Pumps should not be kept very close to the vertical pipe. There must be some starting distance. This could be about 10 to 15% of the vertical distance.

Capabilities of Concrete Pump: *Concrete has been pumped to a height over 400 m and a horizontal distance of over 2000 m. This requires selected high pressure pump and special attention to concrete mix design. It is reported that in February, 1985, a record for vertical concrete pumping of 432 m was achieved at the Estangento sallente power station in the Spanish Pyrenees. A Putzmeister stationary high pressure pump with an S-transfer tube valve was used. This pump had a theoretical output of 120 m^3/h, 180 mm delivery cylinder and an effective concrete pressure of over 200 bar, 630 meter of 125 mm diameter high pressure pipeline was used.*

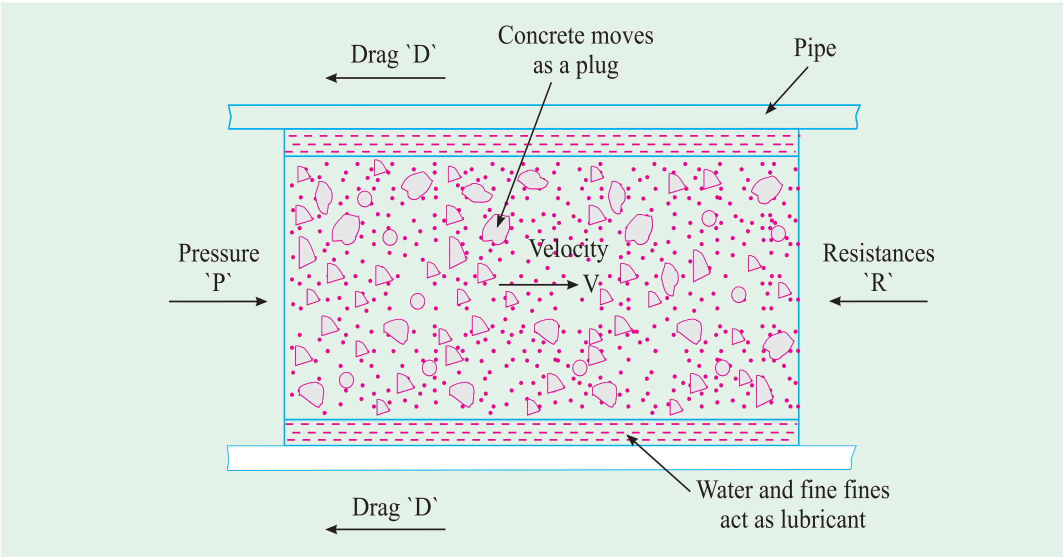
Well pumpable concrete

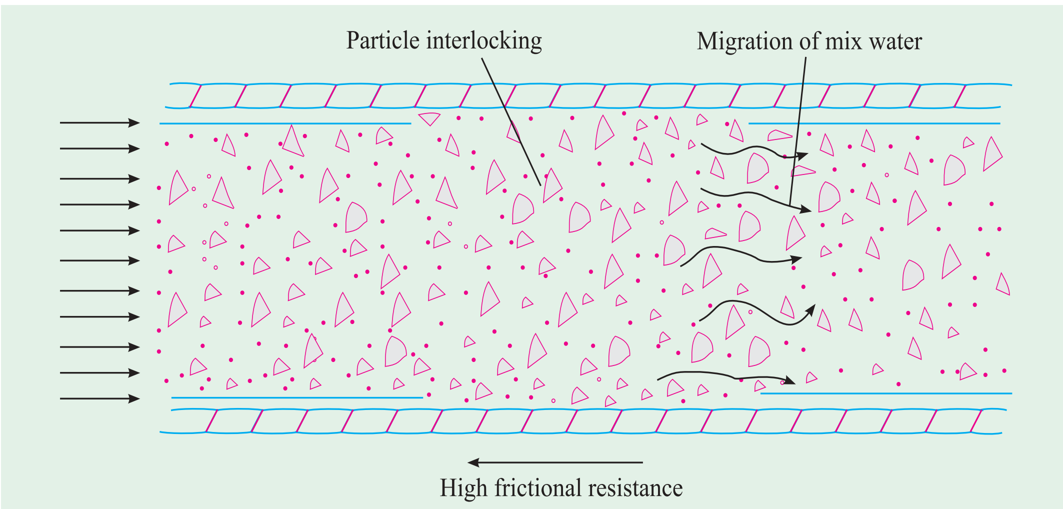
Badly pumpable concrete

For the above work, concrete mix consisted of 506 kg 12 – 25 mm granite aggregate, 362 kg 5 – 12 mm granite aggregate, 655 kg 0 – 5 mm granite sand, 0 – 3 mm river sand, 211 kg cement, 90 kg fly ash and 183 litre water.

Pumpable Concrete : *A concrete which can be pushed through a pipeline is called a pumpable concrete. It is made in such a manner that its friction at the inner wall of the pipeline does not become very high and that it does not wedge while flowing through the pipeline. A clear understanding of what happens to concrete when it is pumped through pipeline is fundamental to any study of concrete pumping. Pumpable concrete emerging from a pipeline flows in the form of a plug which is separated from the pipe wall by a thin lubricating layer consisting of cement paste. The water in the paste is hydraulically linked with the interparticle water layer in the plug. Fig. 6.17 shows the concrete flow under pressure.*

For continuous plug movement, the pressure generated by the flow resistance must not be greater than the pump pressure rating. However, if the concrete is too saturated at higher w/c ratio, the concrete at certain pump pressures may be such that water is forced out of the





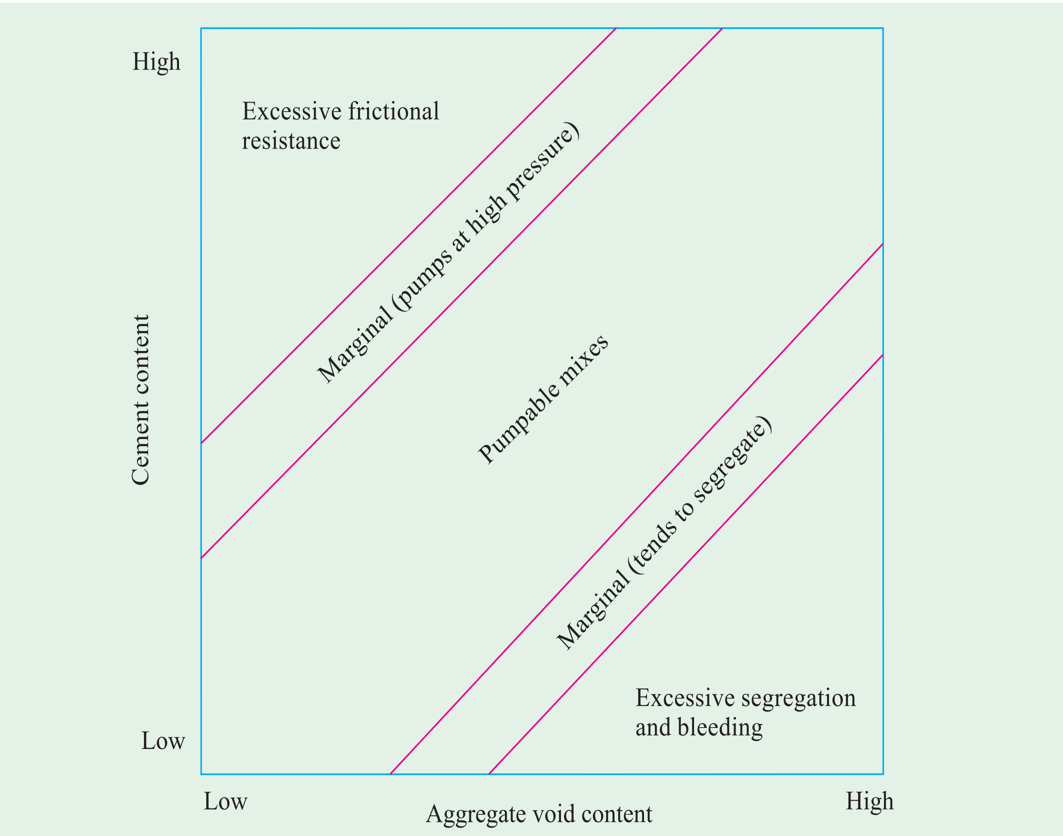
mix, creating an increase in flow resistance and a possible blockage. Fig. 6.18 illustrates such a condition. In other words, a very stiff concrete is not pumpable and also a concrete with high w/c ratio is also not pumpable. It is interesting to note that if a concrete is pumpable, it is implied that it is a good concrete.

Design Considerations for Pumpable Concrete : *The mix is proportioned in such a way that it is able to bind all the constituent materials together under pressure from the pump and thereby avoiding segregation and bleeding. The mix must also facilitate the radial movement of sufficient grout to maintain the lubricating film initially placed on the pipeline wall. The mix should also be able to deform while flowing through bends. To achieve this, the proportion of fines i.e., cement and fine particles below 0.25 mm size (particles below 300 microns Appx.) is of prime importance. The quantities of fine particles between 350 to 400 kg/m^3 are considered necessary for pumpable concrete. The above quantities are not only found necessary for maintaining the lubricating film, but it is important for quality and workability and to cover individual grains.*

There are two main reasons why blockages occur and that the plug of concrete will not move:

- *Water is being forced out of the mix creating bleeding and blockage by jamming, or*
- *There is too much frictional resistance due to the nature of the ingredients of the mix.*

Fig. 6.19. shows the relationship between cement content and aggregate void content and excessive frictional resistance on segregation and bleeding.



While it is important to maintain good grading and low void content, it is not always possible to design pumpable mix around ideal aggregate. Naturally occurring aggregate as well as crushed aggregates are suitable for pumpable mix, but it is essential to be aware of grading, void content and uniformity. The slump of pumpable concrete is kept at 75 mm to collapse range and the diameter of the pipeline is at least 3 – 4 times the maximum size of aggregate.

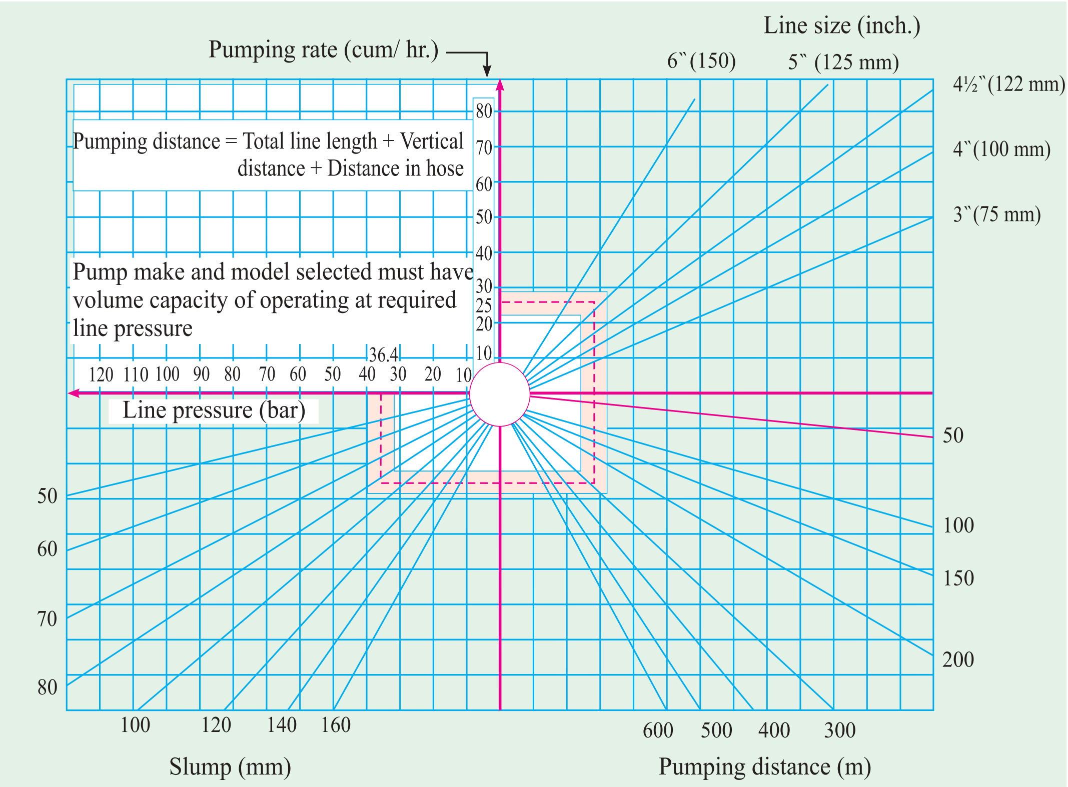
Mix Design process of pumpable concrete will be further dealt in Chapter 11under "Concrete Mix Design."

Choosing the Correct Pump

For choosing the correct pump one must know the following factors

- *Length of horizontal pipe*
- *Length of vertical pipe*
- *Number of bends*
- *Diameter of pipeline*
- *Length of flexible hose*
- *Changes in line diameter*
- *Slump of Concrete.*

Fig. 6.20 hows the line pressure and pumping rate as functions of line diameter, pumping distance and slump. Making use of this nomograph one can find the rated capacity of the pump. This rated capacity should be modified to actual capacity required.



Pressure in the pipe can be estimated using the following guidelines.

• Start up pressure required by pump	= 20 bars
• Every 20 m horizontal pipeline	= 1.0 bar
• Every 4 m Vertical pipeline	= 1.0 bar
• Every 90° bend	= 1.0 bar
• Every 45° bend	= 0.5 bar
• Every pipe coupling	= 0.1 bar
• Every 5 m end hose	= 2.0 bar
• Safety factor	= 10% extra

Example No. 1. *If a trailer mounted pump kept 40 m away from the building and if it is required to pump concrete 100 m vertically, calculate pressure in the pipeline.*

• Start up pressure		20 bars
• Vertical length of pipeline	= 100 m	
∴ Pressure	$= \frac{100}{4}$	25 bars
• Horizontal length	= 40 m	
∴ Pressure	$= \frac{40}{20}$	2 bars
• Couplings 60 Nos		
Pressure	= 60 x 0.1	6 bars
• 90° bends 2 nos		
Pressure	= 2 x 1	2 bars
• End Hose 5 m		
Pressure	= 1 x 2	2 bars
Total Pressure		57 bars
Add 10% as safety factor		6
∴ Total Pressure		63 bars

Example No. 2. *A concrete pump is placed 45 m from a building of height 50 m. The placing boom projects 4 m extra height over the building and it can reach a vertical height of another 25 m with four 90° bends and three 30° bends. The average out put required is 30 m^3/h. The diameter of pipeline is 125 mm. The slump of concrete is 70 mm.*

First find out the theoretical length of pipeline

The length of pipeline = 45 m + 50 m = 95 m

There are four 90° bends and three 30° bends making a total of 4 x 90 + 3 x 30 = 360° + 90° = 450°.

Assuming that the bends have a radius of 1 m, 30° is equivalent to 1 m, and, therefore,

450° is equivalent to $\frac{450}{30} = 15$ *m*

The vertical reach of placing is 25 m, and the bends in the placing boom are assumed to be equivalent to 10 m.

Therefore, the theoretical length of pipeline is 95 + 15 + 25 + 10 = 145 m.

The height to which the concrete has to be pumped is 50 + 4 = 54 m

The static pressure due to vertical pumping is, therefore, 54 x 0.25 = 14 bar

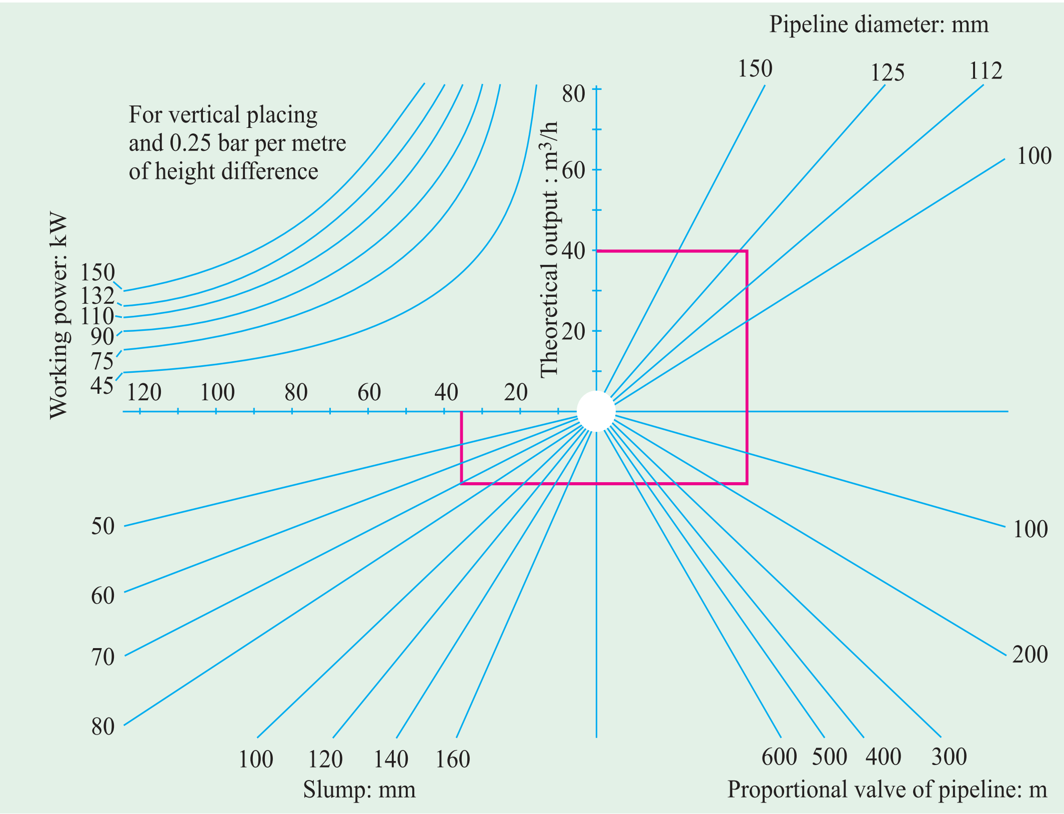
Using the above data i.e., corrected output, pipeline diameter, theoretical length of pipeline and slump, it is possible to arrive at the line pressure using nomograph Fig. 6.21.

On the nomograph Fig 6.21 locate 40 m^3/h output. (30 m^3 x 4/3 = theoretical output = 40 m^3/h). Move across to the right to cut pipeline diameter (125 mm). Then move downwards to meet the theoretical length of pipeline (145 m). Now move to left to intersect the slump line (70 mm). Then move vertically up to meet the pumping pressure line. The reading at this point is shown as 35 bar (Appnox). To this should be added the static pressure of 14 bar, giving a total of 49 bar. The pump chosen, therefore, should have a rated maximum pressure of a figure in excess of 49 bar. The manufacturers will provide their recommended percentage to be added which is normally between 20 and 30%. in this case, the pump required would, therefore, have a line pressure capacity of between 60 and 70 bars.

Common Problems in Pumping Concrete: *The most common problem in pumping concrete is blockage. If concrete fails to emerge at the end of pipeline, if pump is mechanically sound, it would mean that there is blockage somewhere in the system. This will be indicated by an increase in the pressure shown on the pressure gauge. Most blockages occur at tapered sections at the pump end.*

Blockages take place generally due to the unsuitability of concrete mix, pipeline and joint deficiencies and operator's error or careless use of hose end.

It has been already discussed regarding the quality of pumpable concrete. A concrete of right consistency which forms a concrete plug surrounded by lubricating slurry formed inside



the wall of pipeline with right amount of water, well proportioned, homogeneously mixed concrete can only be pumped. It can be rightly said that a pumpable concrete is a good concrete.

Sometimes, high temperature, use of admixtures, particularly, accelerating admixtures and use of high grade cement may cause blockages. Chances of blockage are more if continuous pumping is not done.

A pipeline which is not well cleaned after the previous operation, uncleaned, worn-out hoses, too many and too sharp bends, use of worn out joints are also other reasons for blockages.

Operators must realise and use sufficient quantity of lubricating grout to cover the complete length of pipeline before pumping of concrete. The hose must be well lubricated. Extreme care should be taken in handling the flexible rubber end hose. Careless bending can cause blockages.

Clearing Blockages: *A minor blockage may be cleared by forward and reverse pumping. Excess pressure should not be blindly exerted. If may make the problem worse.*

Sometime shortening the pipeline will reduce pressure and on restarting pumping the blockage gets cleared off.

Tapping the pipeline with hammer and observing the sound one can often locate a blockage.

Blockage could be cleared by rodding or by using sponge ball pushed by compressed air or water at high pressure.

Placing Concrete

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

Paving concrete by slip-forming to get sinusoidal profile for linking with the adjacent slab.

Courtesy : Wirtgen

(*a*) *Placing concrete within earth mould.*
(example: Foundation concrete for a wall or column).

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

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

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

(*e*) *Placing concrete under water.*

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

Mould with floating suspension for simultaneous castig of parapetwall.

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

When concrete is laid in great thickness, as in the case of concrete raft for a high rise building or in the construction of concrete pier or abutment or in the construction of mass concrete dam, concrete is placed in layers. The thickness of layers depends upon the mode of compaction. In reinforced concrete, it is a good practice to place concrete in layers of about 15 to 30 cm thick and in mass concrete, the thickness of layer may vary anything between 35 to 45 cm. Several such layers may be placed in succession to form one lift, provided they follow one another quickly enough to avoid cold joints. The thickness of layer is limited by the method of compaction and size and frequency of vibrator used.

Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush. In case of dam, even sand blasting is also adopted. The old surface is sometimes hacked and made rough by removing all the laitance and loose material. The surface is wetted. Sometimes, a neat cement slurry or a very thin layer of rich mortar with fine sand is dashed against the old surface, and then the fresh concrete is placed.

The whole operation must be progressed and arranged in such a way that, cold joints are avoided as far as possible. When concrete is laid in layers, it is better to leave the top of the layer rough, so that the succeeding layer can have a good bond with the previous layer. Where the concrete is subjected to horizontal thrust, bond bars, bond rails or bond stones are provided to obtain a good bond between the successive layers. Of course, such arrangements are required for placing mass concrete in layers, but not for reinforced concrete.

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

Placing concrete by pump and placing boom.

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 15°C and where ordinary Portland cement is used and adequate curing is done, following striking period can be considered sufficient as per IS 456 of 2000.

Table 6.6. Stripping Time of Formwork

Sr. No.	Type of Formwork	Minimum period before striking formwork
1.	Vertical formwork to columns walls and beams	16 – 24 hours
2.	Soffit formwork to slabs (props to be refixed immediately after removal of formwork)	3 days
3.	Soffit formwork to beams (Props to be refixed immediately after removal of formwork)	7 days
4.	Props to slab	
	spanning up to 4.5 m	7 days
	spanning over 4.5 m	14 days
5.	Props to beam and arches	
	Spanning up to 6 m	14 days
	Spanning over 6 m	21 days

Note: For other cements and lower temperature, the stripping time recommended above may be suitably modified.

Underwater Concreting

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

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

The word "tremie" is derived from the french word hopper.

A tremie pipe is a pipe having a diameter of about 20 cm capable of easy coupling for increase or decrease of length. A funnel is fitted to the top end to facilitate pouring of concrete. The bottom end is closed with a plug or thick polyethylene sheet or such other material and taken below the water and made to rest at the point where the concrete is going to be placed. Since the end is blocked, no water will have entered the pipe. The concrete having a very high slump of about 15 to 20 cm is poured into the funnel. When the whole length of pipe is filled up with the concrete, the tremie pipe is lifted up and a slight jerk is given by *a winch and pully arrangement. When the pipe is raised and given a jerk, due to the weight of concrete, the bottom plug falls and the concrete gets discharged. Particular care must be taken at this stage to see that the end of the tremie pipe remains inside the concrete, so that no water enters into the pipe from the bottom. In other words, the tremie pipe remains plugged at the lower end by concrete. Again concrete is poured over the funnel and when the whole length of the tremie pipe is filled with concrete, the pipe is again slightly lifted and given slight jerk. Care is taken all the time to keep the lower end of the tremie pipe well embedded in the wet concrete. The concrete in the tremie pipe gets discharged. In this way, concrete work is progressed without stopping till the concrete level comes above the water level.*

Fig. 6.22 shows the underwater concreting by tremie.

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

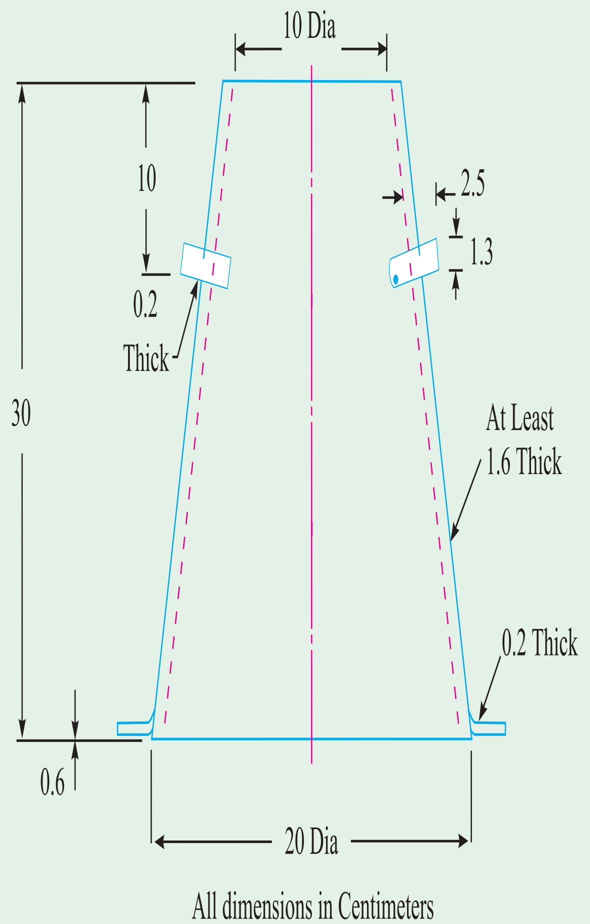


Fig. 6.22. Under Water Concreting by Tremie Method.

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

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

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

Slip-Form Technique

There are special methods of placement of concrete using slip-form technique. Slip-forming can be done both for vertical construction or horizontal construction.

Slip-forming of vertical construction is a proven method of concrete construction generally adopted for tall structures. In this method, concrete is continuously placed, compacted and formwork is pulled up by number of hydraulic Jacks, giving reaction, against jack rods or main reinforcements. The rate of slipping the formwork will vary depending upon the temperature and strength development of concrete to withstand without the support of formwork. In India number of tall structures like chimneys and silos have been built by this technique. Although this method of construction is suitable for uniform shapped structures it was adopted for the core construction of stock exchange building at Bombay having irregular shape and number of openings. The core of 380 feet tall structure was completed in about 38 days. The formwork was slipped at the rate of about 12.5 cm per hour.

The horizontal slip-form construction is rather a new technique in India. It is adopted for road pavement construction. For the first time the slip-form paving method was adopted in Delhi-Mathura concrete Road construction during mid 1990's.

The slip-form pavers were used by many contracting firms in the construction of Mumbai-Pune six lane express highway. The state-of the art method of slip form pavement construction has come to India in a big way.

Slip-form paver is a major equipment, capable of spreading the concrete dumped in front of the machine by tippers or dumpers, compacting the concrete through number of powerful internal needle vibrators and double beam surface vibrators. The paver carries out the smooth finishing operation to the highest accuracy and then texture the surface with nylon brush operating across the lane. The equipment also drops the tie bar at the predetermined interval and push them through and places them at the predetermined depth and recompact the concrete to cover up the gap that are created by the dowel bars. Generally no bleeding takes place because of the stiff consistency of the concrete (2 cm slump) that is designed for placing by slip-form paver. If at all any little bleeding water is there, upon its disappearance, membrane forming curing compound is sprayed on to the textured surface of concrete.

All the above operations are continuously carried out and the slip-form paver crawls continuously on tracked wheel, guided by laser control. Proper alignment to cater for straight line, or curve of any degree with calculated super elevation, or upward or downward gradients are controlled by laser application. Computerised laser control is the backbone of this state-of- the art slip-form paver equipment. The speed of construction *i.e.*, the speed of continuous movement of paver is around 1 meter per minute and in a day of 16 hours working, this equipment can complete about one km of one lane road of width 3.75 m and depth 35 cm.

In the Mumbai-Pune express highway construction, they have used two types of paving equipments namely wirtgen SP 500 and CMI.

They are used for lane by lane construction. Whereas in Europe and the other advanced countries, slip-form pavers capable of completing two or three lanes in one operation are used.

Placing high quality concrete by slip-form technique for a width of 8.5 m.

To feed such a paver, large quantity of concrete of uniform quality is required. In India today, the capacity of batching is a limitation. In Europe continuous batching plants which can supply consistent quality of concrete at a rate of 150 to 250 m^3/hr are available. This rate will make it possible to supply extra wide slip-form paver. Sophistication in road construction has just started in India. With the experience gained, we will be able to produce large quantities of manufactured fine and coarse aggregate of right quality needed for high rate of production of concrete to meet the requirement of multi lane slip-form paver.

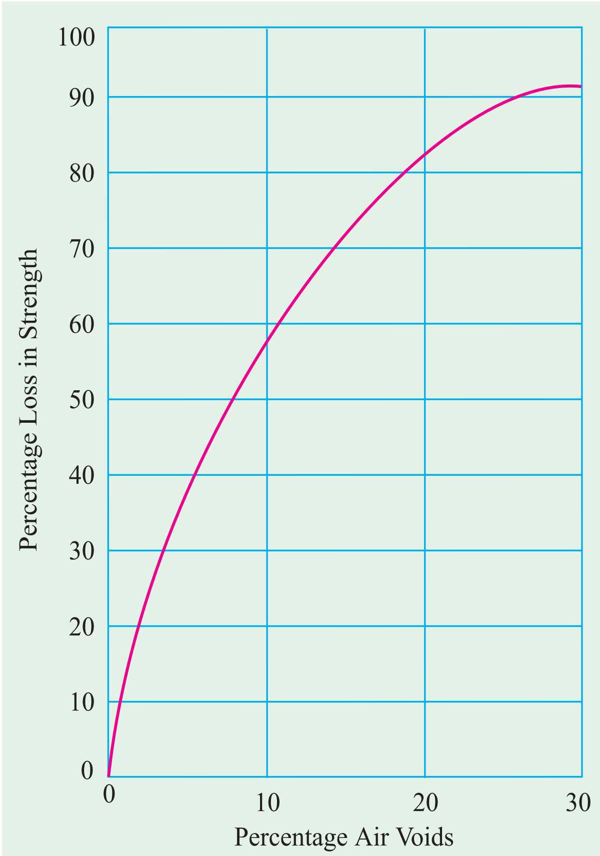
Compaction of Concrete

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. Fig. 6.23 shows the relationship between loss of strength and air voids left due to lack of compaction. It can be seen from the figure that 5 per cent voids reduce the strength of cocrete by about 30 per cent and 10 per cent voids redduce the strength by over 50 per cent. Therefore, it is imperative that 100 per cent compaction of concrete is one of the most important aim to be kept in mind in good concrete-making practices.

It must be borne in mind that 100 per cent compaction is important not only from the point of view of strength, but also from the point of durability. In recent time, durability becomes more important than strength.

Insufficient compaction increases the permeability of concrete resulting in easy entry for aggressive chemicals in solutin, which attack concrete and reinforcement to reduce the durability of concrete. Therefore, 100 per cent compaction of concrete is of paramount importance.



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 100 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,

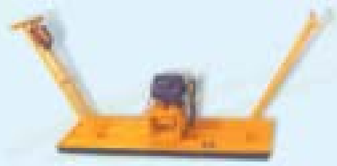


Plate Vibrator

Screed Board Vibrator

Table Vibrator

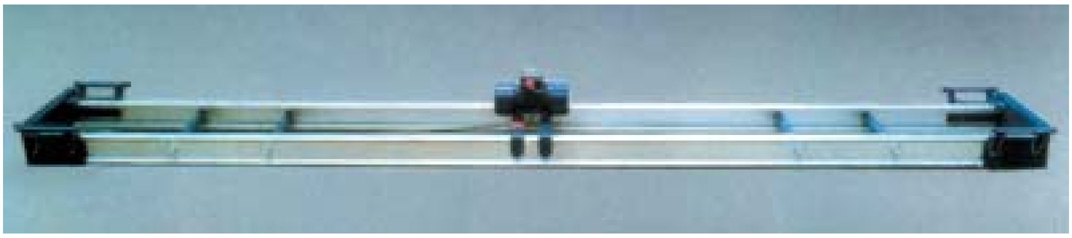
Needle Vibrator
Electric

Needle Vibrator
Petrol

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



Double Beam Screed Board Vibrator

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.

Compaction of concrete by vibration has almost completely revolutionised 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 realised 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.

Vibrating Table

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.

Vibrating Table

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 thorugh compaction is given to the concrete.

Surface Vibrator: Surface vibrators are sometimes knows as, "Screed Board Vibrators". A small vibrator placed on the screed board gives an effective method of compacting and levelling of thin concrete members, such as floor slabs, roof slabs and road surface. Mostly, floor slabs and roof slabs are so thin that internal vibrator or any other type of vibrator cannot be easily employed. In such cases, 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.

General Points on Using Vibrators

Vibrators may be powered by any of the following units:

(*a*) *Electric motors either driving the vibrator through flexible shaft or situated in the head of the vibrator.*

(*b*) *Internal combustion engine driving the vibrator needle through flexible shaft, and*

(*c*) *Compressed-air motor situated near the head of the vibrator.*

Where reliable supplies of electricity is available the electric motor is generally the most satisfactory and economical power unit. The speed is relatively constant, and the cables supplying current are light and easily handled.

Small portable petrol engines are sometimes used for vibrating concrete. They are more easily put out of action by site conditions. They are not so reliable as the electric or compressed-air motors. They should be located conveniently near the work to be vibrated and should be properly secured to their base.

Compressed-air motors are generally quite suitable but pneumatic vibrators are sometimes difficult to manipulate where the compressor cannot be placed adjacent to the work such as on high scaffoldings or at depths below ground level due to the heavy weight of air hoses.

Compressed-air vibrators give trouble especially in cold weather, by freezing at exhaust unless alcohol is trickled into the air line or dry air is used. Glycol type antifreeze agents tend to cause gumming of the vibrator valves. There is also a tendency for moisture to collect in the motor, hence care should be taken to remove the possible damage.

The speed of both the petrol and compressed-air motors tend to vary giving rise to variation in the compacting effect of the vibrator.

Further Instructions on use of Vibrators

Care shall be taken that the vibrating head does not come into contact with hard objects like hardened concrete, steel and wood, as otherwise the impact may damage the bearings. The prime mover should as far as possible, be started only when head is raised or resting on soft support. Similar precautions shall be observed while introducing or withdrawing the vibrator in the concrete to be consolidated. When the space for introduction is narrow, the vibrator should be switched on only after the vibrator head has been introduced into the concrete. Unnecessary sharp bends in the flexible shaft drive shall be avoided.

Vibrators conforming to the requirements of IS 2505-1963 (i.e., Specification for concrete vibrators, immersion type) shall be used. The size and characteristics of the vibrator suitable for a particular job vary with the concrete mix design, quality and workability of concrete, placing conditions, size and shape of the member and shall be selected depending upon various requirements. Guidance regarding selection of a suitable vibrator may be obtained from Table 6.7.

Correct design of concrete mix and an effective control in the manufacture of concrete, right from the selection of constituent materials through its correct proportioning to its placing, are essential to obtain maximum benefits of vibration. For best results, the concrete to be vibrated shall be of the stiffest possible consistency, generally within a range of 0.75 to 0.85 compacting factor, provided the fine mortar in concrete shows at least a greasy wet appearance when the vibrator is slowly withdrawn from the concrete and the material closes over the space occupied by the vibrator needle leaving no pronounced hole. The vibration of concrete of very high workability will not increase its strength; it may on the contrary, cause segregation. Formation of a watery grout on the surface of the concrete due to vibration is an indication that the concrete is too softly made and unsuitable for vibration; a close textured layer of viscous grout may, however, be allowed.

For vibrated concrete, the formwork shall be stronger than is necessary for hand compacted concrete and greater care is exercised in its assembly. It must be designed to take up increased pressure of concrete and pressure variations caused in the neighbourhood of the vibrating head which may result in the excessive local stress on the formwork. More exact details on the possible pressures are not available and much depends upon experience, judgement and the character of work. The joints of the formwork shall be made and maintained tight and close enough to prevent the squeezing out of grout or sucking in of air during vibration. Absence of this precaution may cause honey-combing in the surface of concrete, impairing the appearance and sometimes weakening the structure.

The amount of mortar leakage or the permissible gap between sheathing boards will depend on the desired final appearance of the work but normally gaps larger than 1.5 mm between the boards should not be permitted. Sometimes even narrower joints may be objectionable from the point of view of their effect on the surface appearance of certain structures. The number of joints should be made as few as possible by making the shutter sections large. Applications of mould releasing agents on the formwork, to prevent the adhesion on concrete should be very thin as otherwise they may mix with the concrete under the effect of vibration, and cause air entrainment and blow holes on the concrete surface.

The vibrator may be used vertically, horizontally or at an angle depending upon the nature of the job. But needle vibrators should be immersed in beams and other thick sections, vertically at regular intervals. The concrete to be vibrated shall be placed in position in level layers of suitable thickness not greater than the effective length of the vibrator needle.

The concrete at the surface must be distributed as horizontally as possible, since the concrete flows in slopes while being vibrated and may segregate. The vibration shall, therefore, not be done in the neighbourhood of slopes. The internal vibrator should not be used to spread the concrete from the filling as this can cause considerable segregation of concrete. It is advisable to deposit concrete well in advance of the point of vibration. This prevents the concrete from subsiding non-uniformly and thus prevents the formation of incipient plastic cracks. When the concrete is being continuously deposited to an uniform depth along a member, vibrator shall not be operated too near the free end of the advancing concrete, usually not within 120 cm of it. Every effort must be made to keep the surface of the previously placed layer of concrete alive so that the succeeding layer can be bonded with it by the vibration process. However, if due to unforeseen circumstances the concrete has hardened in the underlying layer to such an extent that it cannot be penetrated by the vibrator but is still fresh (just after initial set) unimposed bond can be achieved between the top and underlying layers by systematically and thoroughly vibrating the new concrete into contact with old.

Height of Concrete Layer

Concrete is placed in thin layers consistent with the method being used to place and vibrate the concrete. Usually concrete shall be placed in a thickness not more than 60 cm and on initial placing in thickness not more than 15 cm. The suprimposed load increasing with the height of the layer will favour the action of the vibrator, but as it is also the path of air forced upwards, it may trap air rising up by vibration. Very deep layers (say more than 60 cm) should, therefore, be avoided although the height of layer can also be one metre provided the vibrator used is sufficiently powerful, as in dams.

Depth of Immersion of Vibrator

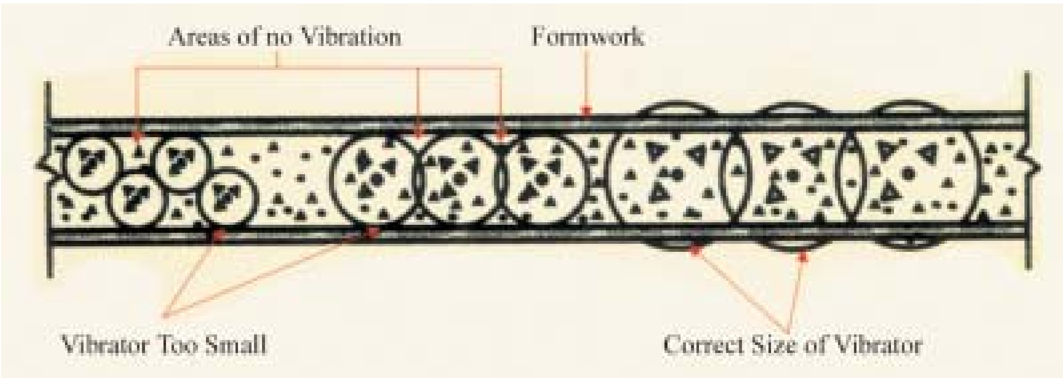
To be fully effective, the active part of the vibrator shall be completely immersed in the concrete. Its compacting action can be usually assisted by maintaining a head of concrete *above the active part of the vibrator, the primary object of which is to press down upon and confine the concrete in the zone of influence of the vibrator. The vibrator head shall be dipped through the filling which is to be consolidated to a further depth of 10 to 20 cm in the lower layer which has already been consolidated so that there is a good combination of various layers and the grout in the lower layer is distributed in the new filling.*

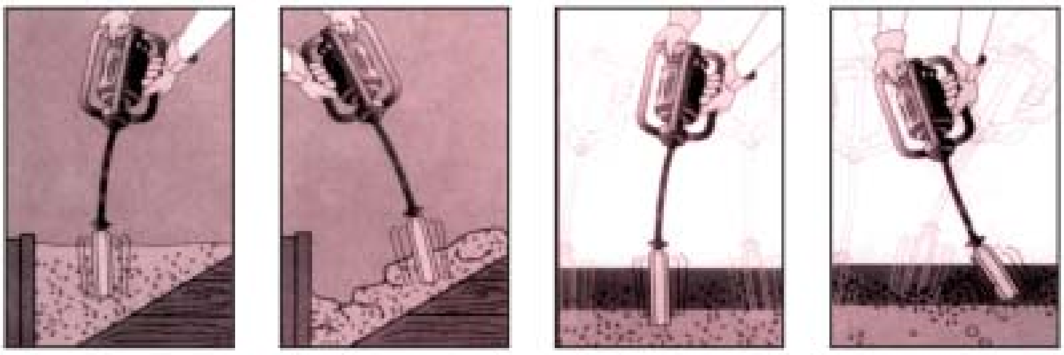
Spacing and Number of Insertion Positions

The points of insertion of the vibrator in the concrete shall be so spaced that the range of action overlap to some extent and the freshly filled concrete is sufficiently compacted everywhere. The range of action varies with the characteristics of the vibrator and the composition and workability of concrete. The range of action and the degree of compaction can be recognized from the rising air bubbles and the formation of a thin shining film around the vibrating head. With concrete of workability of 0.78 to 0.85 compacting factor, the vibrator shall generally be operated at points 35 to 90 cm apart. The specified spacing between the dipping positions shall be maintained uniformly throughout the surface of concrete so that the concrete is uniformly vibrated.

Speed of Insertion and Withdrawal of the Vibrating Head

The vibrating head shall be regularly and uniformly inserted in the concrete so that it penetrates of its own accord and shall be withdrawn quite slowly whilst still running so as to allow redistribution of concrete in its wake and allow the concrete to flow back into the hole behind the vibrator. The rate of withdrawal is determined by the rate at which the compaction in the active zone is completed. Usually a speed of 3 cm/s gives sufficient consolidation without undue strain on the operator. Further concrete is added as the vibrators are





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withdrawn so as to maintain the head of the concrete until the lift of the concrete is completed.

Duration of Vibration

New filling shall be vibrated while the concrete is plastic, preferably within one hour. The duration of vibration in each position of insertion is dependent upon the height of the layer, the size and characteristics of the vibrator and the workability of the concrete mix. It is better to insert the vibrating head at a number of places than to leave it for a long time in one place, as in the latter case, there is a tendency for formation of mortar pocket at the point of insertion of the vibrator.

The vibrator head shall be kept in one position till the concrete within its influence is completely consolidated which will be indicated by formation of circular shaped cement grout on the surface of concrete, appearance of flattened glistening surface and cessation of the rise of entrapped air. Vibration shall be continued until the coarse aggregate particles have blended into the surface but have not disappeared.

The time required to effect complete consolidation is readily judged by the experienced vibrator operator through the feel of the vibrator, resumption of frequency of vibration after the short period of dropping off of frequency when the vibrator is first inserted. Doubt about the adequacy of vibration should always be resolved by further vibration; well proportioned concrete of the correct consistency is not readily susceptible to over-vibration.

Vibrating Concrete at Junctions with Hardened Concrete

In cases where concrete has to be joined with rock or hardened concrete, defects can occur owing to the layers nearest to the hardened concrete not being sufficiently vibrated. In such cases the procedure given below should be adopted:

The hardened concrete surface should be prepared by hacking or roughening and removing laitance, greasy matter and loose particles. The cleaned surface shall be wetted. A cement sand grout of proportion 1:1 and of creamy consistency is then applied to the wet surface of the old concrete, and the fresh concrete vibrated against it.

Vibrating the Reinforced Concrete

The reinforcement should be designed to leave sufficient space for the vibrating head. Where possible, the reinforcement may be grouped so that the width of groups of bars does not exceed 25 cm and a space of 7.5 cm exists between the groups of bars to allow the vibrator to pass freely; the space between the bars in any group may be reduced to two-thirds of the nominal size of coarse aggregate.

When the reinforcements lie very close to each other, greater care is taken in vibrating so that no pockets or collections of grout are formed. Except where some of the concrete has already set and provided that the reinforcement is adequately supported and secured, the vibrator may be pressed against the reinforcement.

Vibrating near the Formwork

For obtaining a smooth close textured external surface, the concrete should have a sufficient content of matrix. The vibrator head shall not be brought very near the formwork as this may cause formation of water whirls (stagnations), especially if the concrete containing too little of fine aggregate. On the other hand, a close textured surface may not be obtained, if the positions of insertion are too far away from the formwork. The most suitable distance of the vibrator from the formwork is 10 to 20 cm. With the vibration done at the correct depth

Table 6. 7. Characteristics and Applications of Immersion Vibrators

Sr. No.	Characteristics of Vibrator				Application
	Length of the Vibrating Needle mm	Diameter of the Vibrating Needle mm	Recommended frequency of vibration under no Load State, Min Vibration VPM	* Recommended vibration Acceleration (operation in Air), Min g^{+}	
(1)	(2)	(3)	(4)	(5)	(6)
(i)	up to 350	up to 35	9000	30 to 50	Plastic, workable concrete in very thin members and confined places and for fabrication of laboratory test specimens. Suitable as an auxiliary to larger vibrators in prestressed work, where many cables and ducts cause congestion in the forms.
(ii)	250 to 500	Over 35 up to 60	9000	Over 30 up to 60	Plastic, workable concrete in thin walls, columns, beams, precast piles, light bridge decks, and along construction joints.
(iii)	250 to 700	Over 60 up to 75	7000	Over 60 up to 75	Plastic, workable concrete in general construction, such as walls, columns. beams, precast piles, heavy floors, bridge deck and roof slabs. Auxiliary vibration adjacent to forms mass concrete and pavements.

Table 6.7 (Contd.)

(1)	(2)	(3)	(4)	(5)	(6)
(iv)	300 to 450	Over 75 up to 90	7000	Over 75 up to 90	Mass and structural concrete deposited in increments up to 2 m^3 in heavy construction in relatively open forms, in power houses, heavy bridge piers and foundations and for auxiliary vibration in foundations and for auxiliary vibration in dam construction near forms and around embedded items and reinforcing steel.
(v)	200 to 475	Over 90	6000	Over 90	Mass concrete containing 15 cm. aggregate deposited in increments up to 8 m^3, in gravity dams, large piers, massive walls, etc. Two or more vibrators will be required to operate simultaneously to melt down and consolidate increments of concrete of 4 m^3 or greater volume deposited at one time in the forms.

* Value of acceleration measured in concrete should not be less then 75 per cent of the values given above.

† Acceleration due to gravity.

and with sufficient grout rising up at the formwork, the outside surface will generally have a close textured appearance. In the positions of formwork difficult to reach and in concrete walls less than 30 cm thick it is preferable to use vibrators of small size which can be brought to the required place and which will not excessively strain the formwork.

Vibrating High Walls and Columns

While designing the formwork, reinforcement, as well as the division of layers for high walls and columns, it should be kept in mind that with the usual driving shaft lengths it is not possible to penetrate the vibrating head more than three metres in the formwork. In the case of higher walls and columns it is recommended to introduce the shaft driven vibrating needle through a side opening into the formwork. For use with high walls and columns, the flexible driving shaft can be brought to a length of six to eight metres or even more by using adopter pieces. The motor-in-head type vibrators are more useful for the purpose in cases where a very long current cable can be used for sinking the vibrator to a greater depth.

Over-Vibration

There is a possibility of over-vibration while trying to achieve thorough vibration, but it is exceedingly unlikely in well proportioned mixes containing normal weight aggregates. Generally, with properly designed mixes, extended vibration will be only a waste of effort without any particular harm to the concrete.

However, where the concrete is too workable for the conditions of placing, or where the quantity of mortar is excess of the volume of voids in the coarse aggregate, or where the grading of the aggregate is unsatisfactory, over-vibration will encourage segregation, causing migration of the lighter and smaller constituents of the mix to the surface, thereby producing layer of mortar or laitance on the surface, and leakage of mortar through the defective joints in the formwork. This may produce concrete with poor resistance to abrasion and attack by various agencies, such as frost, or may result in planes of weakness where successive lifts are being placed. If over vibration occurs, it will be immediately evident to an experienced vibrator operator or supervisor by a frothy appearance due to the accumulation of many small air bubbles and the settlement of coarse aggregates beneath the surface. These results are more liable to occur when the concrete is too wet and the proper correction will be to reduce the workability (not the vibration), until the evidence of over-vibration disappears during the amount of vibration judged necessary to consolidate the concrete and to eliminate air-bubble blemishes.

Output of Immersion Vibrator

Output of compacted concrete may be taken as 3 to 5 cubic metre per hour depending upon the consistency of the mix for a light type of vibrator, having a centrifugal force of about 200 kg. The out-turn will be as much as 12 to 25 cubic metre per hour for a heavy type of vibrator having a centrifugal force of 450 kg.

Re-vibration

Re-vibration is delayed vibration of concrete that has already been placed and compacted. It may occur while placing successive layers of concrete, when vibrations in the upper layer of fresh concrete are transmitted to the underlaying layer which has partially hardened or may be done intentionally to achieve certain advantages.

Except in the case of exposed concrete and provided the concrete becomes plastic under vibration, re-vibration is not harmful and may be beneficial. By repeated vibration over a long *period (repetition of vibration earliest after one hour from the time of initial vibration), the quality of concrete can be improved because it rearranges the aggregate particles and eliminates entrapped water from under the aggragae and reinforcing steel, with the consequence of full contact between mortar and coarse aggregate or between steel and mortar and thus produces stronger and watertight concrete. Plastic shrinkage cracks as well as other disturbances like hollow space below the reinforcement bars and below the coarse aggregate, can thereby be closed again provided the concrete becomes soft again when the vibrator head in introduced. Re-vibration of concrete results in improved compressive and bond strength, reduction of honey-comb, release of water trapped under horizontal reinforcing bars and removal of air and water pockets.*

Re-vibration is most effective at the lapse of maximum time after the initial vibration, provided the concrete is sufficiently plastic to allow the vibrator to sink of its own weight into the concrete and make it momentarily plastic.

Vibration of Lightweight Concrete

In general, principles and recommended practices for consolidation of concrete of normal weight hold good for concrete made with light weight aggregate, provided certain precautions are observed.

There is always a tendency for light weight pieces of aggregate to rise to the surface of fresh concrete, particularly under the action of over-vibration; and a fairly stiff mix, with the minimum amount of vibration necessary to consolidate the concrete in the forms without honey-comb is the best insurance against undesirable segregation. The rise of lightweight coarse aggregate particles to the surface, caused by over-vibration resulting from too wet a mix makes finishing difficult if not impossible.

Curing of Concrete

We have discussed in Chapter I the hydration aspect of cement. 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 cource, the rate of hydration is fast to start with, but countinues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23 for hydration and a water/cement ratio of 0.15 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water cement ratio of 0.38 would satisfy the requirement of

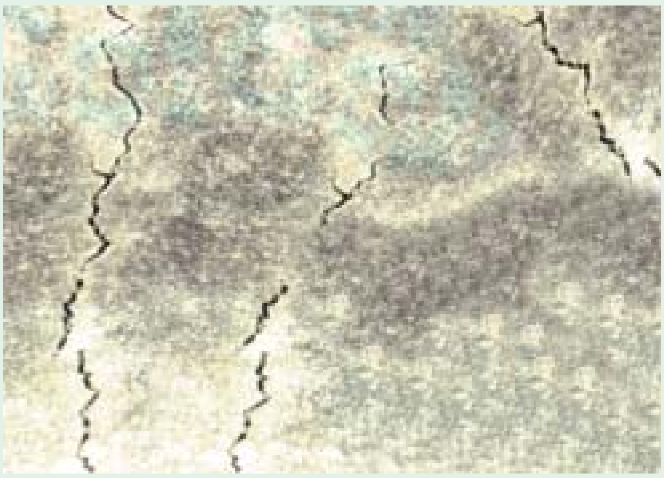
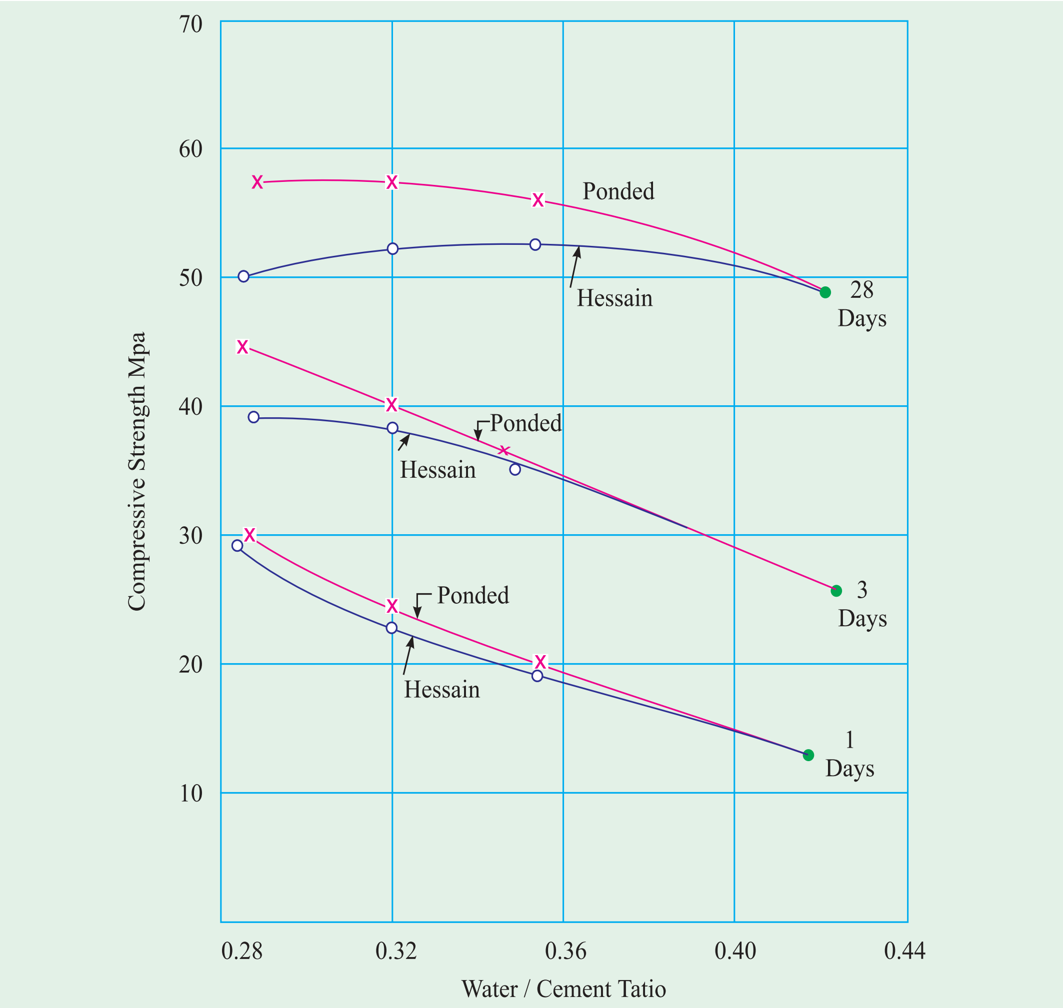


Fig.6.24. Cracks on concrete surface due to inadequate curing.



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.

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. Fig. 5.33 on page 173, Chapter 5, shows the drying behaviour of concrete. 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 a satisfactory moisture content and a favourable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet 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 Fig. 6.24, shows plastic shrinkage cracks on concrete surface due to quick drying and inadequate early curing. 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. Fig. 6.25, shows the influence of curing by ponding and wet covering.[6.4]

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

Membrane curing by spraying.

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 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.

Curing vertical surface by wet covering.

Enough has been written in Chapter 5 on the modern curing compounds that are available today. 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.

For further details refer Chapter 5 where more information about curing compounds. Method for determining the efficiency of curing compounds etc., are given.

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.

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.*

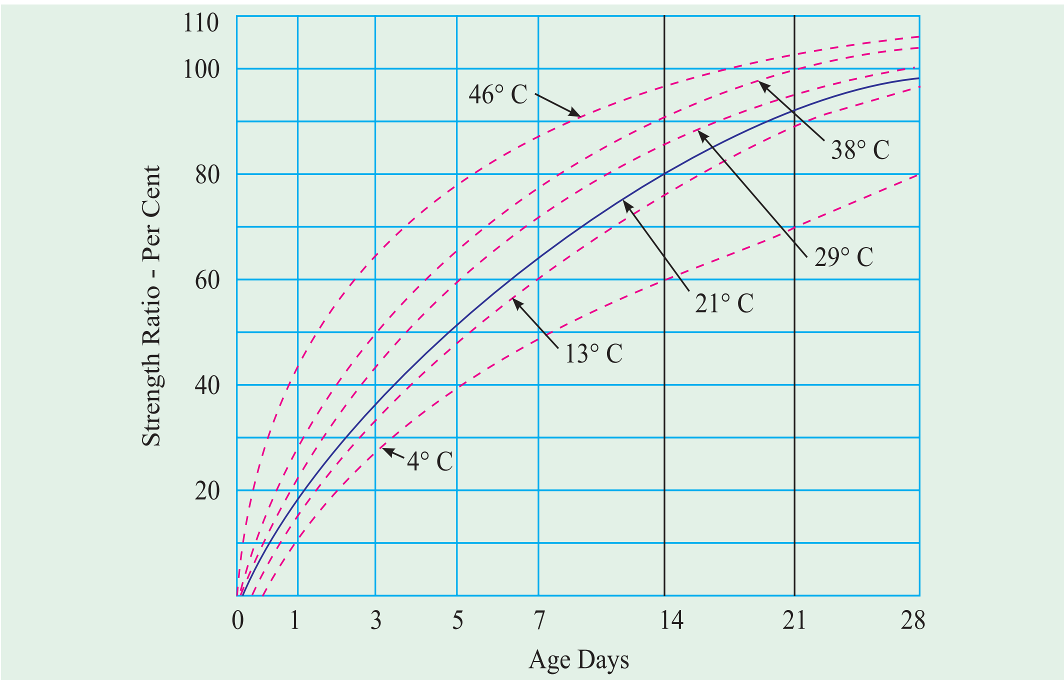
(*c*) *Curing by Infra-red radiation.*

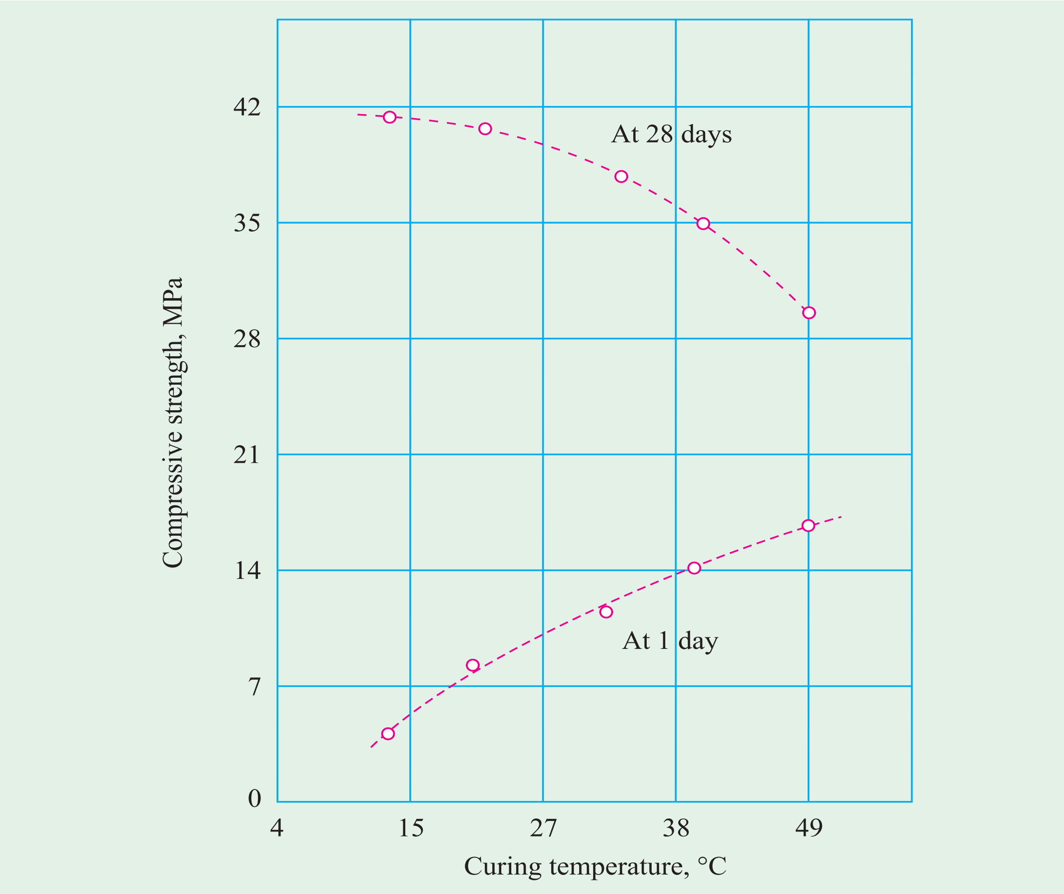
(*d*) *Electrical curing.*

Steam curing at ordinary pressure

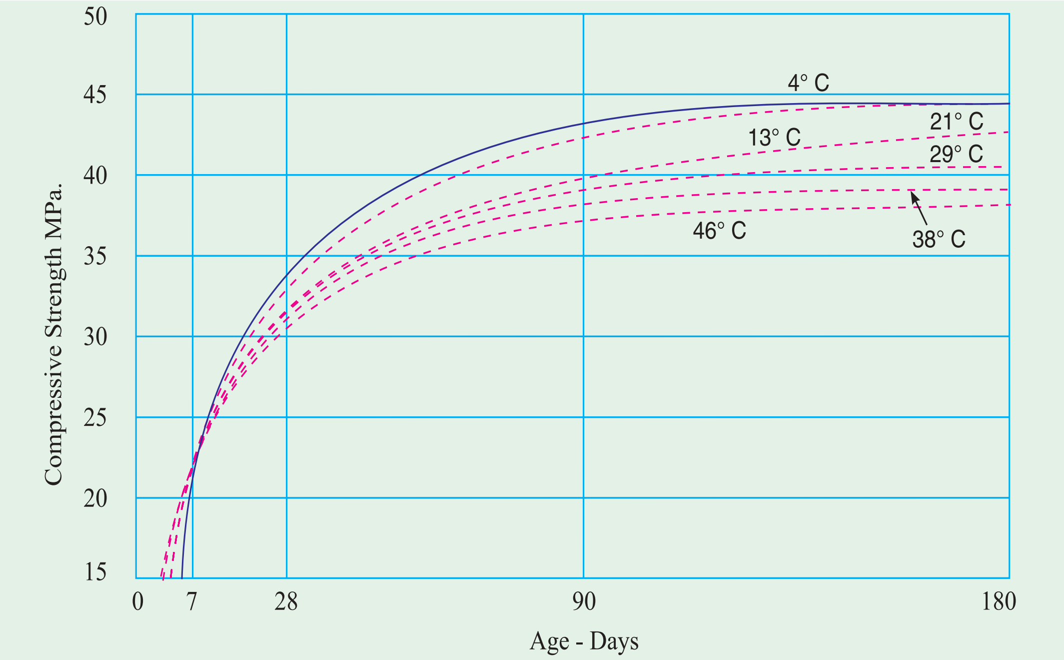
This method of curing is often adopted for pefabricated concrete elements. Application of steam curing to in situ construction will be a little difficult task. However, at some places it has been tried for in situ construction by forming a steam jacket with the help of tarpaulin or thick polyethylene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

Beam under steam curing.

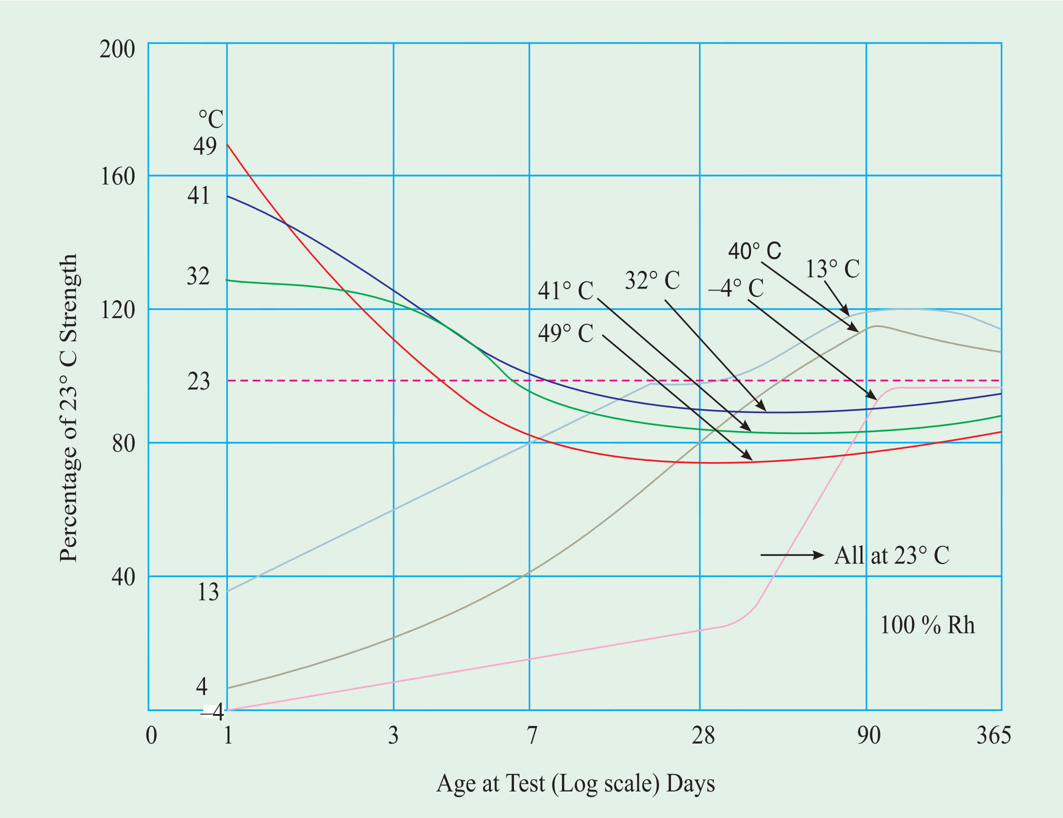


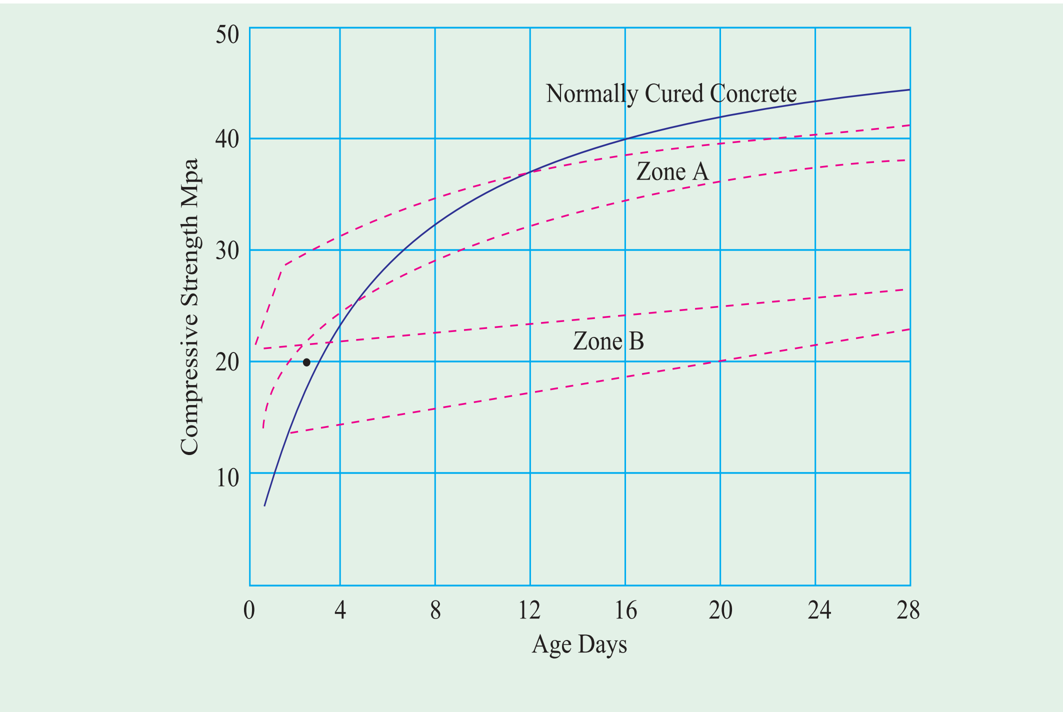


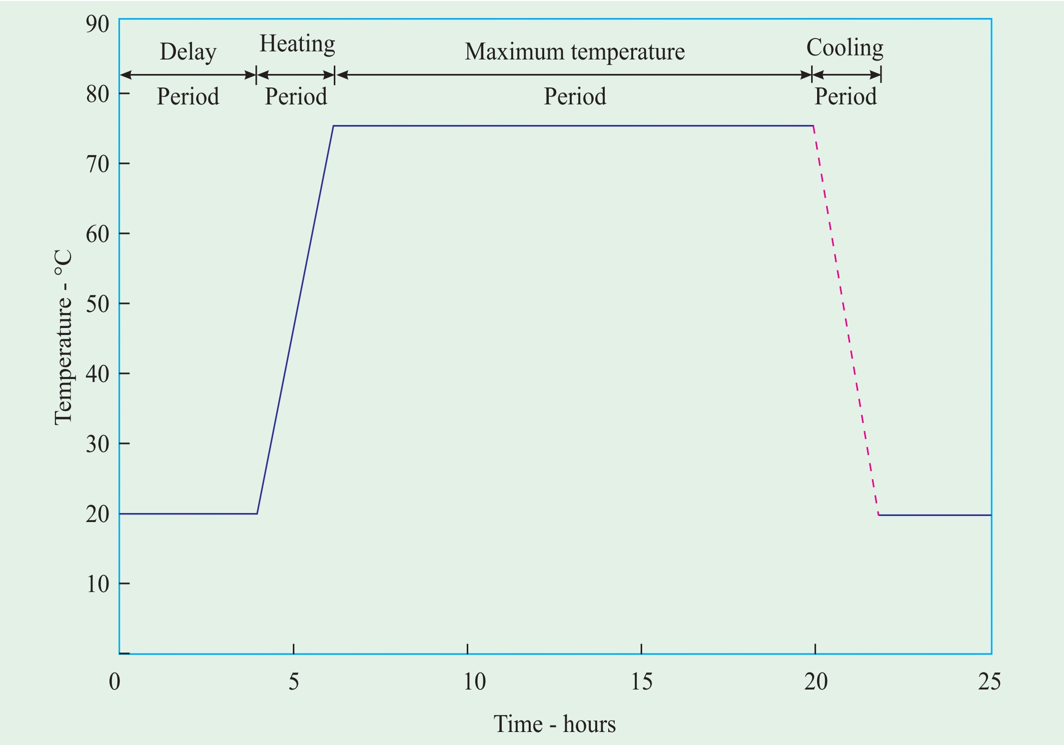
42
35
28
21
14
7
0
4
15
27
38
49
At 28 days
At 1 day
Compressive strength, MPa
Curing temperature, °C



50
45
40
35
30
25
20
15
0
7
28
90
180
4° C
13° C
21° C
29° C
46° C
38° C
Compressive Strength MPa.
Age - Days


200
160
120
80
40
°C
49
41
32
23
13
4
–4
Percentage of 23° C Strength
41° C
49° C
32° C
40° C
–4° C
13° C
All at 23° C
100 % Rh
0
1
3
7
28
90
365
Age at Test (Log scale) Days


50
40
30
20
10
Compressive Strength Mpa
Normally Cured Concrete
Zone A
Zone B
0
4
8
12
16
20
24
28
Age Days



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.

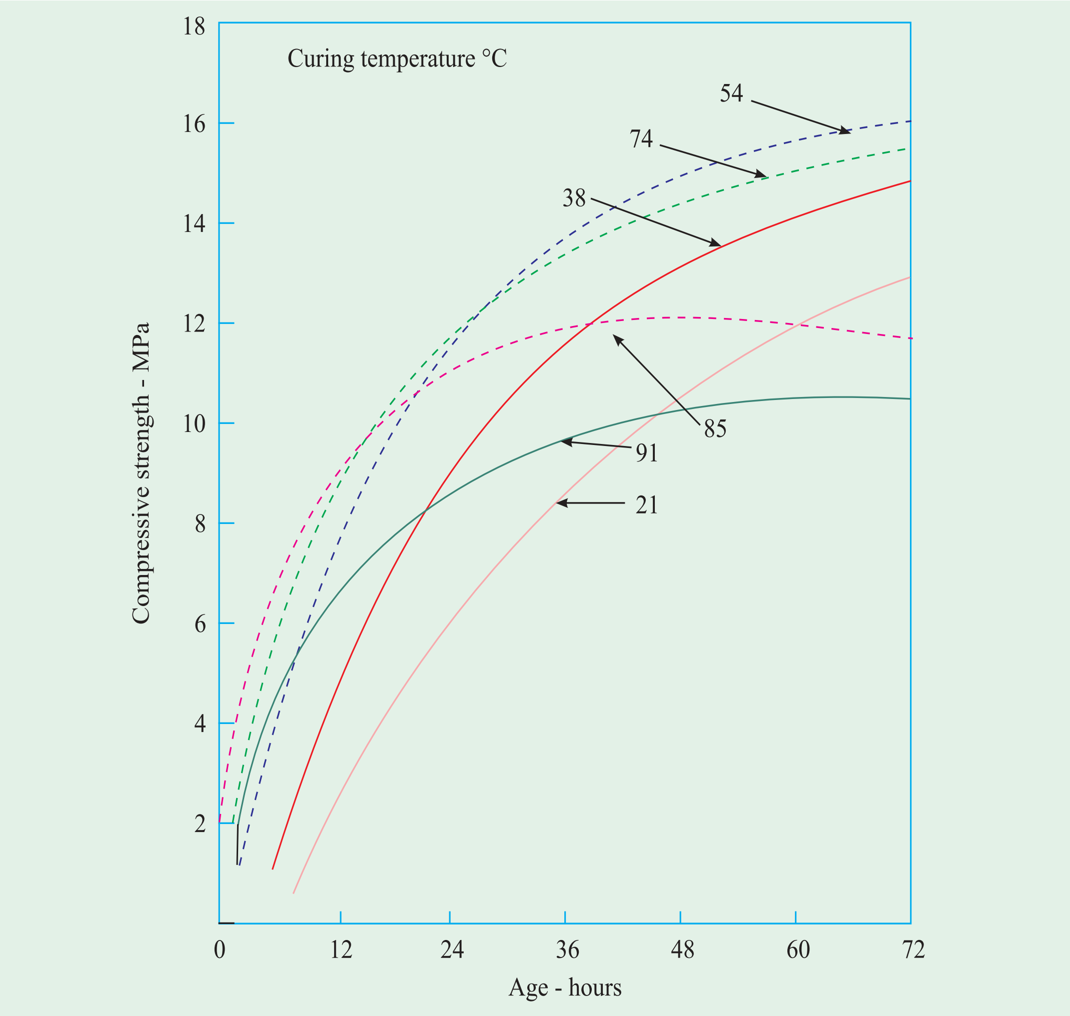
In large prefabricated factories they have tunnel curing arrangements. The tunnel of sufficient length and size is maintained at different temperature starting from a low temperature in the beginning of the tunnel to a maximum temperature of about 90°C at the end of the tunnel. The concrete products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

The influence of curing temperature on strength of concrete is shown in Fig. 6.26 and 6.28.[6.5]

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". Figure 6.29 shows the effect of temperature on strength of concrete. It can be seen from Figure 6.29 that the concrete subjected to higher temperature at early age, no doubt attains higher strength at a shorter duration, but suffers considerable retrogression of strength. Fig. 6.29 . On the contrary, concrete cured at a comparatively lower temperature takes longer time to develop strength but the strength attained will not be lost at later ages. 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. The strength of such rapidly heated concrete falls in the zone B and the strength of gradually heated concrete falls within the zone A in Figure. 6.30.

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 number 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.*

A typical steam curing cycle at ordinary pressure is shown Fig. 6.31and typical strength of steam cured concrete at different temperature in shown in Fig. 6.32.

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 1/6 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.

When to Start Curing and how Long to Cure

Many a time an engineer at site wonders, how early he should start curing by way of application of water. This problem arises, particularly, in case of hot weather concreting. In an arid region, concrete placed as a road slab or roof slab gets dried up in a very short time, say within 2 hours. Often questions are asked whether water can be poured over the above concrete within two hours to prevent the drying. The associated problem is, if water is applied within say two hours, whether it will interfere with the water/cement ratio and cause harmful effects. In other words, question is how early water can be applied over concrete surface so that uninterrupted and continued hydration takes place, without causing interference with the water/cement ratio. The answer is that first of all, concrete should not be allowed to dry fast in any situation. Concrete that are liable to quick drying is required to be covered with wet gunny bag or wet hessian cloth properly squeezed, so that the water does not drip and at the same time, does not allow the concrete to dry. This condition should be maintained for 24 hours or at least till the final setting time of cement at which duration the concrete will have assumed the final volume. Even if water is poured, after this time, it is not going to interfere with the water/cement ratio. However, the best practice is to keep the concrete under the wet gunny bag for 24 hours and then commence water curing by way of ponding or spraying. Of course, when curing compound is used immediately after bleeding water, if any, dries up, the question of when to start water curing does not arise at all.

There is a wrong notion with common builders that commencement of curing should be done only on the following day after concreting. Even on the next day they make arrangements and build bunds with mud or lean mortar to retain water. This further delays *the curing. Such practice is followed for concrete road construction by municipal corporations also. It is a bad practice. It is difficult to set time frame how early water curing can be started. It depends on, prevailing temperature, humidity, wind velocity, type of cement, fineness of cement, w/c used and size of member etc. The point to observe is that, the top surface of concrete should not be allowed to dry. Enough moisture must be present to promote hydration. To satisfy the above conditions any practical steps can be undertaken, including the application of fine spray or fogging without disturbing surface finish. Such measures may be taken as early as two hours after casting. It is pointed out that early curing is important for 53 grade cement.*

Incidentally, it is seen that test cubes cast at site are allowed to dry without covering the top with wet covering. They are allowed to dry in the hot sun. Such cubes develop cracks and show low strength when crushed. It is usual that they complain about poor quality of cement or concrete.

Regarding how long to cure, it is again difficult to set a limit. Since all the desirable properties of concrete are improved by curing, the curing period should be as long as practical. For general guidance, concrete must be cured till it attains about 70% of specified strength. At lower temperature curing period must be increased.

Since the rate of hydration is influenced by cement composition and fineness, the curing period should be prolonged for concretes made with cements of slow strength gain characteristics. Pozzolanic cement or concrete admixed with pozzolanic material is required to be cured for longer duration. Mass concrete, heavy footings, large piers, abutments, should be cured for at least 2 weeks.

Finishing of road pavement

To assertain the period of curing or stripping of formwork, cubes or beams are cast and kept adjacent to the structure they represent and cured by the same method. The strength of these cubes or beams at different intervals of time would give better idea about the strength development of structures. The above method does not truly indicate the strength development of massive girder subjected to steam curing because of size difference of cubes and girders.

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.

Formwork Finishes

Concrete obeys the shape of formwork i.e., centering work. By judiciously assembling the formwork either in plane surface or in undulated fashion or having the joints in a particular "V" shaped manner to get regular fins or groves, a pleasing surface finish can be given to concrete. The architect's imaginations can be fully exploited to give many varieties of look to the concrete surface. The use of small battens can give a good look to the concrete surface.

A pre-fabricated wall unit cast between steel formwork having very smooth surface using right proportioning of materials can give such a nice surface which can never be obtained by the best masons. Similarly, the prefabricated floor units can have such a fine finish at the ceiling which cannot be obtained by the best masons with the best efforts. These days with the cost of labour going up, attention is naturally directed to the self-finishing of the concrete surface,

Mechanical trowel for finishing factory floor.
Sometimes surface hardener is sprinkled and finished.

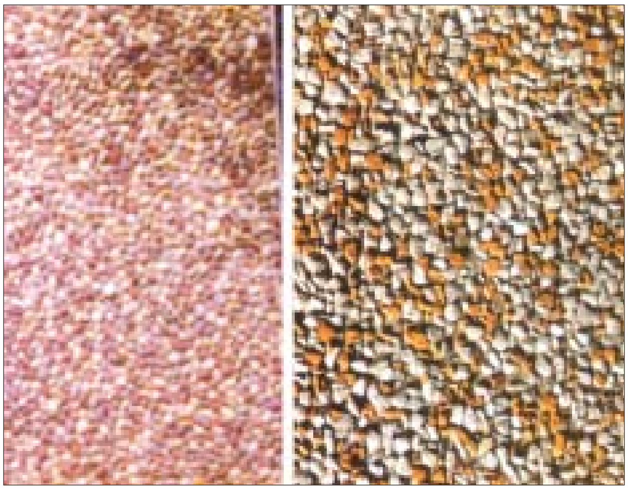
particularly, for floor slabs, by the use of good formwork material such as steel sheets or shuttering type plywood.

Surface Treatment

This is one of the widely used methods for surface finishing. The concrete pavement slab is required to be plane but rough to exhibit skid resistance, so is the air-field pavements and road slabs. Concrete having been brought to the plane level surface, is raked lightly or broomed or textured or scratched to make the surface rough.

A domestic floor slab is required to be smooth, wear resisting and crack-free. The technique of finishing the concrete floor requires very careful considerations. The proportioning of the mix must be appropriate without excess or deficient of matrix. Water/cement ratio should be such that it provides the just required consistency to facilitate spreading and good levelling, yet to give no bleeding. Surface must be finished at the same rate as the placing of concrete. Particular care must be taken to the extent and time of trowelling. Use of wooden float is better to start with but at the end steel trowel may be used. In all the operation, care must be taken to see that no laitance is formed and no excessive mortar or water accumulates on the surface of the floor, which reduces the wear resistance of the floor. The excess of mortar at the surface causes craziness due to increased shrinkage. Achieving a good surface finish to a concrete floor requires considerable experience and devotion on the part of the mason. A hurried completion of surface operation will make a poor surface.

Often concrete is placed at a much faster rate than the speed of finish by the masons with the result that concrete dries up and mason is not able to bring the concrete to a good level. He resorts to applying extra rich mortar to bring the floor surface to good level. This practice of applying rich mortar spcecially made to the surface is not desirable. This practice, firstly reduces the bond. Secondly, reduces the strength and wear resistance than the homogeneous concrete. Thirdly, mortar shrinks more than that of concrete. Therefore, application of a thick layer of mortar over set concrete is objectionable. It is a good practice to the finish the floor with the matrix that comes to the top of the concrete due to the compaction of concrete and by working with mason's tamping rule. In case the above is not possible, use of extra mortar may be permitted to avoid very poor surface finish. But it is necessary to observe the following precautions:



Exposed aggregate finish

(a) The mortar composition be the same as that of concrete.

(b) It should be applied as thin a layer as possible before the base concrete is hardened, and rubbed smooth.

(c) Sprinkling of dry cement in good quantity is not a good practice, however a small quantity may be permitted to reduce the bad effect of bleeding, taking care to see that it does not make the top layer too rich.

Exposed Aggregate-Finish: *This is one of the methods of giving good look to the concrete surface. The beauty can be further enhanced by the use of coloured pebbles or quartz. One or two days after casting, the matrix is removed by washing the surface with water or by slight brushing and washing. One face of the aggregate particles will adhere to the matrix and the other face gets exposed. This exposed surface will give a pleasing look. Sometimes, retarding agent is applied to the formwork surface. The matrix at the surface being in contact with the retarding agent, does not get hardened, whereas rest of the portion gets hardened. On washing or light brushing, the unhardened matrix gets washed out, exposing the aggregate.*

Applied finish work done at CME

Sometimes use of hydrochloric acid solution made up of one part of acid to six parts of water is used for washing the concrete surface to expose the aggregate. The acid attacks the cement and enables it to be brushed off. Care must be taken that the workman should use rubber-gloves and on completion of washing by the acid, the surface should be treated with alkaline solution to neutralise any remaining acid. This method of using acid should not be applied for concrete made with limestone aggregate.

Bush Hammering: *A Bush Hammer is a tool with a series of pyramidal teeth on its face. They may be hand operated or pneumatically or electrically operated. Hand tools are suitable for small jobs but power operated equipment is used for large surface.*

Bush Hammer gives rapid blows to the concrete surface and not only removes the outer cement film but also breaks some of the exposed aggregate giving a bright, colourful and attractive surface. Very pleasant effects may be obtained by carefully arranging large aggregates at the surface and later removing the matrix by bush hammer.

Concrete should be at least three weaks old, before it is bush hammered. Otherwise, there is a danger of whole pieces of aggregates being dislodged. The quality of concrete which is to be treated this way by bush hammering must be of high quality and good workmanship.

Applied Finish: *The term applied finish is used to denote the application of rendering to the exteriors of concrete structures. The concrete surface is cleaned and roughned and kept wet for sufficiently long time. Over this a mortar of proportion of about 1:3 is applied. This mortar rendering can be given any required pleasant finish, such as cement stippling either fine or coarse,* ***combed finish****, keying, renderings etc.*

*Sometimes this rendering applied on wall is pressed with sponge. The sponge absorbs cement and water exposes sand particles. The sponge is washed and again rubbed against the surface. With the repetition of this process, the surface gets a finish, known as "****Sand Facing****".*

*A wet plastic mix of three parts of cement, , one part of lime, six parts of sand and 4 parts of about 5 mm size peagravel aggregate is thrown against wall surface by means of a scoop or plasterer's trowel. This finish is known as "****Rough Cast Finish****".*

Upon a 10 mm thick coat of one part of cement, one part of lime and five parts of sand, while it is still plastic, is thrown about 6 mm size selected well-washed pebbles. This kind of finish is known as "**Pebble Dash**".

The latest method of finish given to the concrete surface is known as "**Fair Crete**" finish. This rendering can be given to the concrete *in situ* or better still to the concrete panels. Such panels are used as cladding to the concrete structures.

Fair crete is nothing but a highly air-entrained mortar (air-entrainment is to be extent of 25 per cent) mixed with chopped jute fibre. This mortar is spread and pressed by a mould having different designs. The impression of the mould is translated into the mortar. Air entrained mortar being foamy in nature takes the impression of the mould. A wide variety of designs and murals can be translated to the air entrained mortar surface. The jute fibre increases the tensile strength of the fair crete.

Miscellaneous Finishes: Non-slip Finish: Surface of ramps, railway platforms, surroundings of swimming pools etc., are required to posses a highly nonslip texture. To obtain this quality, an abrasive grit is sprinkled over the surface during the floating operations. The surface is lightly floated just to embed the abrasive grit at the surface. Sometimes, epoxy screed is also given to the surface over which silica sand is sprinkled while the epoxy is still wet.

Coloured Finish: Principal materials used for colouring concrete are:

(*a*) Pigment admixtures (*b*) Chemical stains
(*c*) Paints (*d*) White cement (e) Coloured concrete.

Pigment admixtures may be added integrally to the topping mix, blended with the dry cement, or pigments may be dusted on to the topping immediately on application of screed. Of all the methods, mixing integrally with the mortar is the best method, next to using coloured cements. Sometimes, certain chemicals are used to give desirable colour to the concrete surface. Similarly, cement based paints or other colour paints are also used.

White cement is used in different ways to give different look to the concrete. White and coloured cements have been used as toppings in factory floor finish.

Recently RMC (India), a Ready Mix Concrete supplying company, have started supplying Ready Mixed coloured concrete in various colours. They incorporate certain percentage of fibres in this concrete to take care of shrinkage cracks and to impart other desirable properties to the concrete.. Such coloured concrete can be used indoors or outdoor application as a substitute to ordinary concrete.

Wear Resistant Floor Finish: A wear resisting quality of a concrete floor surface can be improved by using solutions of certain chemicals known as "Liquid Harderners". They include, fluosilicates of magnesium and zinc, sodium silicate, gums and waxes. When the compounds penetrate the pores in the topping, they form crystalline or gummy deposits and thus tend to make the floor less pervious and reduce dusting either by acting as plastic binders or making the surface harder.

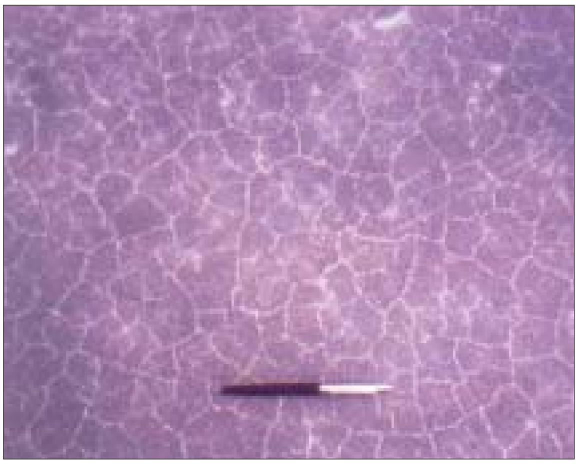
Sometimes, iron filing and iron chips are mixed with the toppings and the floor is made in a normal manner. The rusting of the iron filings and chips increases in volume and thereby makes the concrete dense giving the floor better wear resistance. They are known as "Ironite floor toppings". Fibre reinforced concrete also has demonstrated a better wear-resistance quality in case of road and airfield slabs. We have already discussed about Wear Resistant floor finish in Chapter 5 under construction chemicals. Attention is drawn to the present day availability and application Epoxy Paint, Epoxy mortar, self levelling Epoxy screed etc., for the *use of Wear Resistant floor and decorative floor finish. They are widely used in modern construction.*

Requirement of a good finish: *A good concrete floor should have a surface which is durable, non-absorptive, suitable texture, free from cracks, crazing and other defects. In other words, the floor should satisfactorily withstand wear from traffic. It should be sufficiently impervious to passage of water, oils or other liquids. It should possess a texture in keeping with the required appearance, should be easy to clean and be safe against slipping. It should structurally be sound and must act in unison with sub-floor.*

Grinding and Polishing: *Floors when properly constructed using materials of good quality, are dustless, dense, easily cleaned and attractive in appearance. When grinding is specified, it should be started after the surface has hardened sufficiently to prevent dislodgement of aggregate particles and should be continued until the coarse aggregates are exposed. The machine used should be of approved type with stones that cut freely and rapidly. The floor is kept wet during the grinding process and the cuttings are removed by spraying and flushing with water. After the surface is ground, air holes, pits and the other blemishes are filled with a thin grout composed of one part of fine carborundum grit and one part of portland cement. This grout is spread over the floor and worked into the pits with the straight edge after which it is rubbed into the floor with a grinding machine. When the fillings are hardened for seven days, the floor is given final grinding.*

Craziness: *While we are discussing about the surface finish it will be pertinent to discuss the craziness i.e., the development of fine shallow hair cracks on concrete surface.*

The surface appearance of concrete is often spoilt by a fairly close pattern of hair cracks which may appear within the first year, occasionally after longer periods. The cracks do not penetrate deep into the concrete and do not indicate any structural weakness. They are most obvious immediately after the surface of the concrete has dried when wetted they become prominent. It is not possible to state any precautions which will definitely prevent craziness but its occurrence can be minimised. Craziness is due to drying shrinkage or carbonation or due to differential shrinkage between the surface of the concrete and the main body of the concrete. This differential shrinkage is accentuated if the skin is richer than the parent concrete. It is known that drying shrinkage is greatest when the concrete dries up fast after casting. The first precaution to take, therefore, is very careful curing so that the initial drying period is extended over as long a time as possible so that the shrinkage of the outer skin is kept in conformity with the shrinkage of the main body of the concrete. Steep moisture gradients between the surface and the interior of the concrete must be avoided if possible. Cracking will not occur if the concrete is sufficiently strong to resist the tensile forces caused by differential shrinkage but it does not appear possible to prevent crazing by making a very strong concrete.



Craziness in the surface of concrete.

The object must therefore be to minimise shrinkage of the surface skin and this is best achieved by adequate curing and by taking measures to prevent shrinkage by avoiding too rich surface. The following precautions will help greatly:

(*a*) *Trowelling the surface as little as possible and in particular avoiding the use of a steel float.*

(*b*) *Avoiding the use of rich facing mixes, say, not richer than 1:3.*

(*c*) *Use of as low a water-cement ratio as possible consistent with adequate compaction.*

(*d*) *Avoiding grouting processes or rubbing the surface with neat cement paste.*

(*e*) *Over vibration which results in bringing too much slurry to the top or side. (adjacent to formwork).*

Crazing may also be due to carbonation and thermal effects. A cement-rich skin is liable to expand and contract more with difference in temperature than the interior of the concrete. The wetting and drying process is, however, a far more potent factor for causing craziness. The most important causes of crazing are thermal stresses and long term drying shrinkage.

Whisper Concrete Finish : *One of the disadvantages of Concrete Roads is that they produce lot of noise when vehicles travel at high speed, due to friction between tyres and hard road surface. In Europe the noise level has become intolerable to the people living by the side of roads where about a lakh of vehicles move at a speed of about 120 km per hour. Belgium was the first country to take measure to reduce noise pollution.*

It may be recalled that, texturing or brooming is done as a surface finish for the new road pavement construction to provide skid resistance. Over the time, the texturing gets worn out and the surnace becomes smooth. When it rains, the pool of water on the smooth concrete surface causes a phenomenon called "Hydroplaning" when vehicle move at high speed, which results in loss of control and skidding.

Concrete roads needs roughening and resurfacing after some years of use. This is done by regrooving. Regrooving is nothing but cutting and creating grooves about 2 mm deep across the vehicular movement. This is a costly and laborious practice. Instead, Belgium authorities tried exposed aggregate finish. On the smoothened road surface, they overlaid 40–50 mm of concrete, having a maximum size of 6–8 mm coarse aggregate. The surface of new concrete, while still green, was sprayed with a retarder consisting of glucose, water and alcohol. It was immediately covered by polyethylene sheet. After about 8–36, hours, the polyethylene sheet is removed and the road surface was swept and washed with stiff rotating bristle brushes. The top unset cement mortar to a depth of about 1.5 to 2 mm is removed exposing the aggregate, making the surface rough enough for safe high speed vehicular movement.

When vehicles moved at high speed on such exposed aggregate surface it was found to every ones surprise that noise level was much reduced than normal concrete surface. In fact, it was found that noise level was lower than the case of black-topped road pavement. Further trials were conducted and it was confirmed that exposed aggregate finish provides not only skid resistance but also reduces the noise. The Belgian authorities called it as ***"whisper"*** *concrete.*

Mostly in many continental countries where concrete pavements are popular, they provide 40–50 mm layer of whisper concrete. They found that there is very little difference in cost between regrooving and providing whisper concrete. It was also seen that providing a *white topping, that is, providing concrete pavement over bituninous pavement, adoption of whisper concrete gave good economy.*

In U.K., they took up the use of whisper concrete pavement during 1995, and has given good guide lines for adoption of whisper concrete.

Some of the important guidelines are:

- *Under standard highway conditions, a concrete road should consist of cement bound sub-base, between 150–200 mm thick. On top of this, there should be 200 mm of continuously reinforced concrete pavement (CRCP) followed by 50 mm of whisper concrete surfacing.*
- *Normally 8 mm size coarse aggregate should be used for whisper concrete layer. Not more than 3% of these should be oversize and 10% undersize.*
- *The flakiness index should be less than 25%.*
- *Coarse aggregate should form around 60% of whisper concrete. Sand should be very fine.*
- *Spray retarder consisting of glucose, water and alcohol. They cover the surface with polyethylene sheet.*
- *After 8 to 36 hours, remove the polyethylene sheet and brush the surface with mechanically rotating stiff bristle to remove cement mortar from the top 1.5 mm.*

As far as India is concerned, whisper concrete is not going to be a necessity for some years to come.

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Top