

## UNIT-3

# HARDENED CONCRETE

### Introduction

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses.

The compressive strength of concrete is generally determined by testing cubes or cylinders made in laboratory or field or cores drilled from hardened concrete at site or from the non-destructive testing of the specimen or actual structures. Strength of concrete is its resistance to rupture.

### Water/Cement Ratio

Strength of concrete primarily depends upon the strength of cement paste. That the strength of cement paste depends upon the dilution of paste or in other words, the strength of paste increases with cement content and decreases with air and water content.

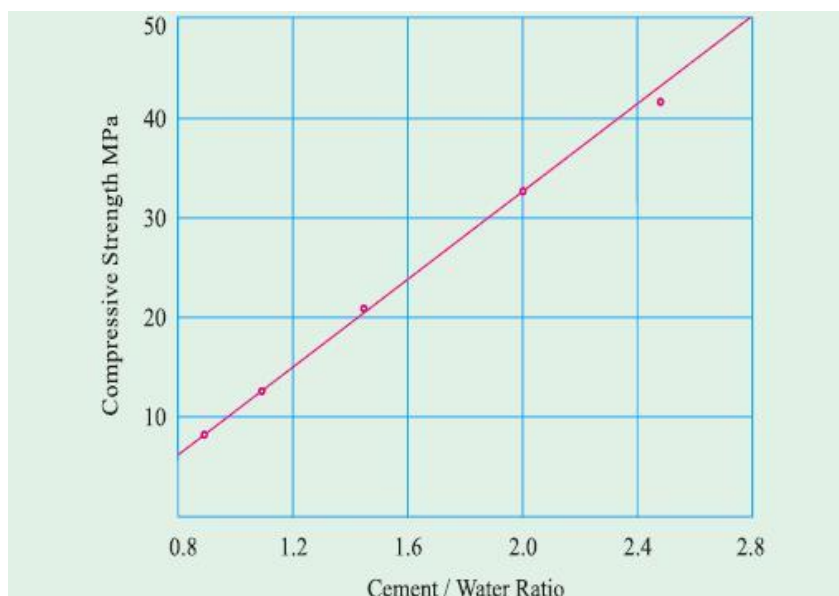
In 1918 **Abrams** presented his classic law in the form:

$$S = A/B^x$$

where  $x$  = water/cement ratio by volume and for 28 days results the constants  $A$  and  $B$  are 14,000 lbs/sq. in. and 7 respectively.

### Abrams water/cement ratio law

States that the strength of concrete is only dependent upon water/cement ratio provided the mix is workable. In the past many theories have been propounded by many research workers. But Abrams' water/cement ratio law stood the test of time and is held valid even today as a fundamental truth in concrete-making practices. The relation between the water/cement ratio and strength of concrete is shown in Fig.



It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand compacted.

In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids. The graph showing the relationship between the strength and water/cement ratio is approximately hyperbolic in shape.

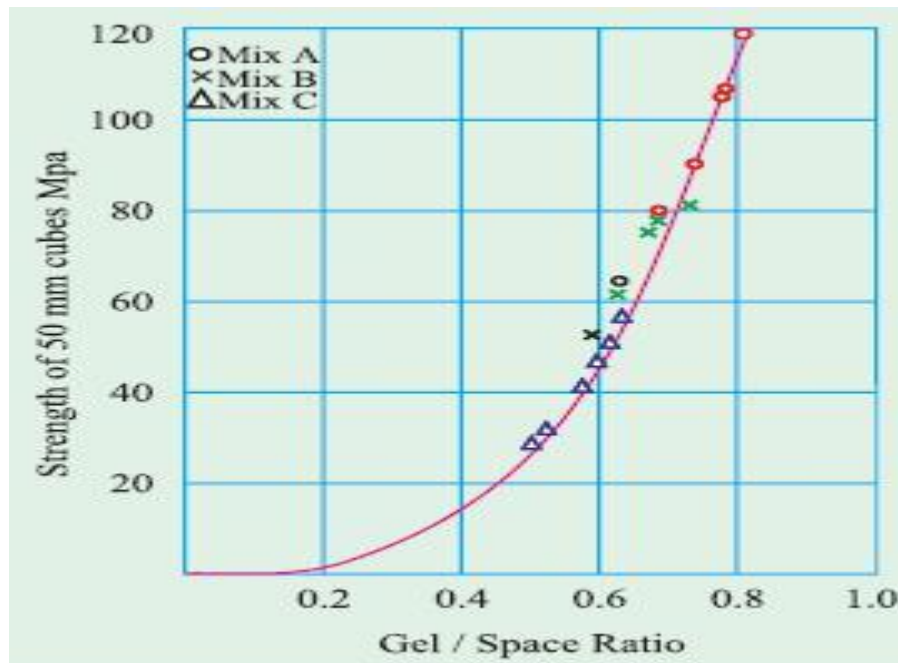
### Gel/Space Ratio

Many research workers commented on the validity of water/cement ratio law as propounded by Duff Abrams. They have forwarded a few of the limitations of the water/cement ratio law and argued that Abrams water/cement ratio law can only be called a rule and not a law because Abrams' statement does not include many qualifications necessary for its validity to call it a law.

This ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of volumes of the hydrated cement and of the capillary pores.

Power's experiment showed that the strength of concrete bears a specific relationship with the gel/space ratio. He found the relationship to be  $240 x^3$ , where  $x$  is the gel/space ratio and 240 represents the intrinsic strength of the gel in MPa for the type of cement and specimen used.

Fig. shows the relationship between strength and gel/space ratio.



It is pointed out that the relationship between the strength and water/cement ratio will hold good primarily for 28 days strength for fully compacted concrete, whereas, the relationship between the strength and gel/space ratio is independent of age. Gel/space

ratio can be calculated at any age and for any fraction of hydration of cement. The following examples show how to calculate the gel/space ratio.

### Calculation of gel/space ratio for complete hydration

Let C = weight of cement in gm.

V<sub>c</sub> = specific volume of cement = 0.319 ml/gm.

W<sub>o</sub> = volume of mixing water in ml.

Assuming that 1 ml. of cement on hydration will produce 2.06 ml of gel,

Volume of gel = C x 0.319 x 2.06

Space available = C x 0.319 + W<sub>o</sub>

Gel/Space ratio :

$$x = \frac{\text{Volume of gel}}{\text{Space available}}$$

$$= \frac{0.657 C}{(0.319C + W_o)}$$

### Calculation of gel/space ratio for partial hydration

Let α = Fraction of cement that has hydrated

Volume of gel = C x α x 0.319 x 2.06

Total space available C V<sub>c</sub> α + W<sub>o</sub>

Gel/space ratio = x =  $\frac{2.06 \times 0.319 \times C \times \alpha}{0.319 C + W_o}$

There is a lot of difference between the theoretical strength of concrete and actual strength of concrete. Actual strength of concrete is much lower than the theoretical strength estimated on the basis of molecular cohesion and surface energy of a solid assumed to be perfectly homogeneous and flawless. The actual reduction of strength is due to the presence of flaws.

Cement paste in concrete contains many discontinuities such as voids, fissures, bleeding channels, rupture of bond due to drying shrinkage and temperature stresses etc. It has been difficult to explain how exactly these various flaws contribute to the reduction in actual strength of concrete.

### Gain of Strength with Age

The concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age. It is customary to assume the 28 days strength as the full strength of concrete. Actually concrete develops strength beyond 28 days also. Earlier codes have not been permitting to consider this increase of strength beyond 28 days for design purposes.

The increase in strength beyond 28 days used to get immersed with the factor of safety. With better understanding of the material, progressive designers have been trying to reduce the factor of safety and make the structure more economical. In this direction, the increase in strength beyond 28 days is taken into consideration in design of structures. After gradation of OPC the present day cements particularly 53 grade cements, being

ground finer, the increase in strength after 28 days is nominal. Most of the strength developments in respect of well cured concrete will have taken place by 28 days.

## HARDENED CONCRETE

The following table gives the grades of concrete as per IS-456 of 2000

**Table: Grades of Concrete as per IS - 456 of 2000**

<i>Group</i>	<i>Grade Designation</i>	<i>Specified characteristic compressive strength of 150 mm cube at 28 days in N/mm<sup>2</sup></i>
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

**Table : Permissible stresses in Concrete  
All values in N/mm<sup>2</sup> (IS 456 of 2000)**

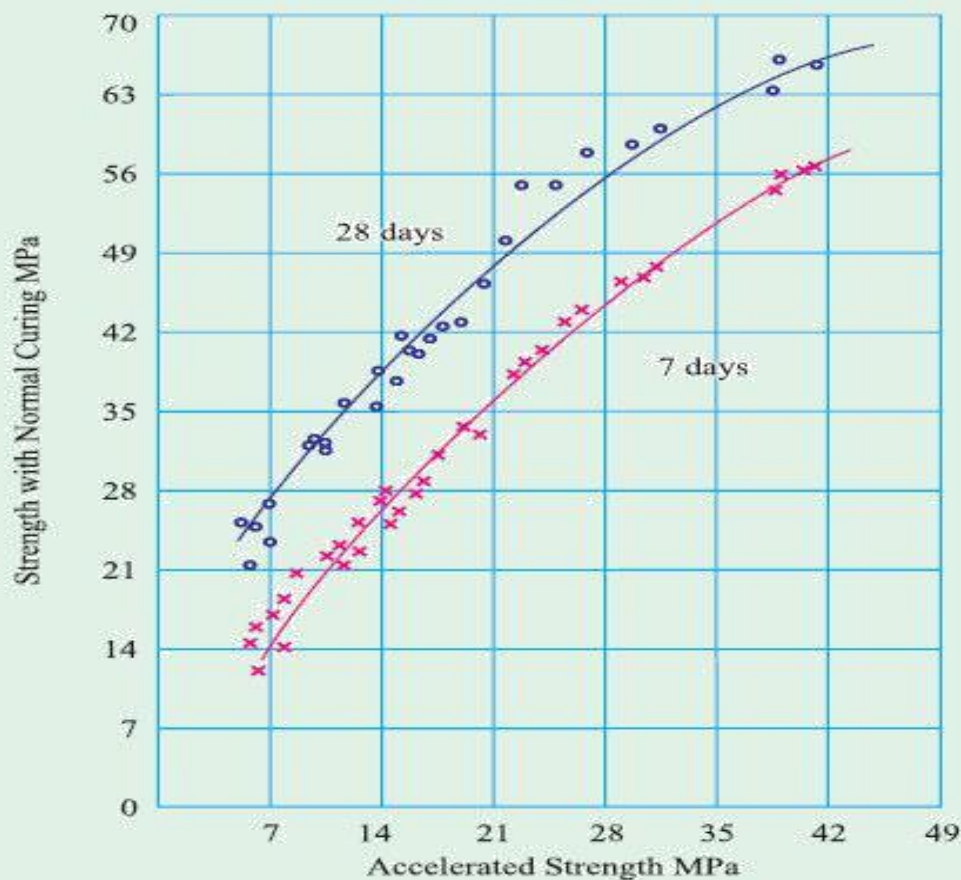
<i>Grade of concrete</i>	<i>Permissible stress in compression</i>		<i>Permissible stress in Bond (average) for Plain Bars in tension</i>
	<i>Bending</i>	<i>Direct</i>	
M 10	3.0	2.5	—
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

**Note:** The bond stress may be increased by 25 per cent for bars in compression.

## Accelerated Curing test

In the accelerated curing test the standard cubes are cast, they are covered with top plate and the joints are sealed with special grease to prevent drying. Within 30 minutes of adding water, the cubes having sealed effectively, are placed in an air-tight oven which is then switched on. The oven temperature is brought to 93°C in about one hour time. It is kept at this temperature for 5 hours. At the end of this period the cubes are removed from oven, stripped, cooled, and tested. The time allowed for this operation is 30 minutes.

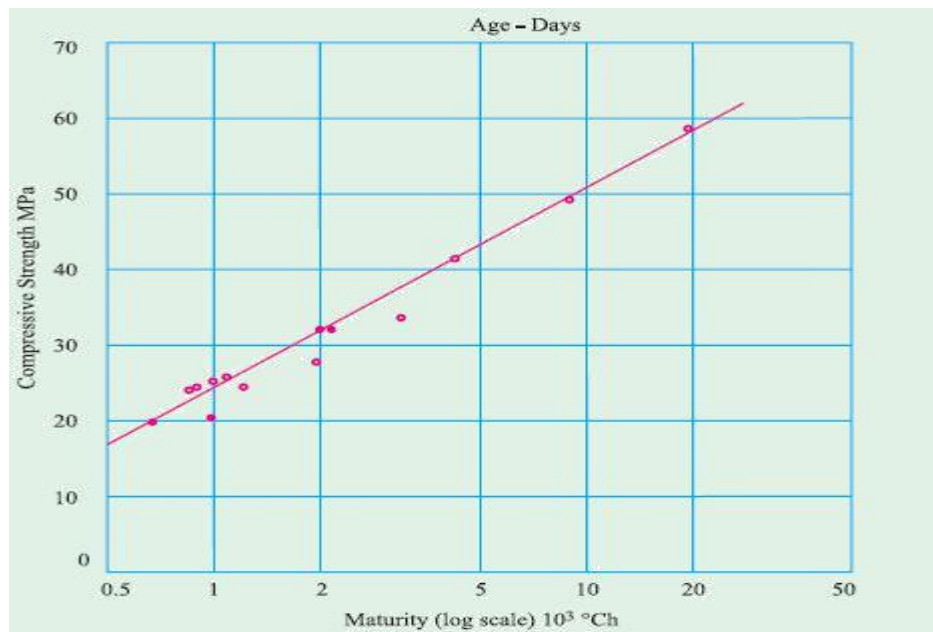
The strength of concrete is determined within 7 hours of casting and this accelerated strength shows good relationship with 7 and 28 days strengths of normally cured concrete. Fig. shows relationship between accelerated strength and normally cured concrete strength at 7 and 28 days. One of the main factors that affects the rate of gain of strength is the fineness of cement. It has been estimated that particles of cement over 40 micron in size contribute to the compressive strength of concrete only over long periods, while those particles smaller than 25 to 30 micron contribute to the 28 days strength, those particles smaller than 20 to 25 micron contribute to the 7 days strength, and particles smaller than 5 to 7 micron contribute to the 1 or 2 days strength.



## Maturity Concept of Concrete

While dealing with curing and strength development, we have so far considered only the time aspect. It has been pointed out earlier that it is not only the time but also the temperature during the early period of hydration that influences the rate of gain of strength of concrete. Since the strength development of concrete depends on both time and temperature it can be said that strength is a function of summation of product of time and temperature. This summation is called maturity of concrete.

$$\text{Maturity} = \sum (\text{time} \times \text{temperature})$$



Strength at any maturity as a percentage of strength at maturity of  $19,800^\circ\text{Ch}$ . =  $A + B \log_{10} \{ (\text{maturity}) / 10^3 \}$

The values of coefficients, A and B depend on the strength level of concrete. The values are given in Table

Table Plowman's Coefficients for Maturity Equation

Strength after 28 days at $18^\circ\text{C}$ (Maturity of $19,800^\circ\text{Ch}$ ): MPa	Coefficient	
	A	B
Less than 17.5	10	68
17.5 – 35.0	21	61
35.0 – 52.5	32	54
52.5 – 70.0	42	46.5

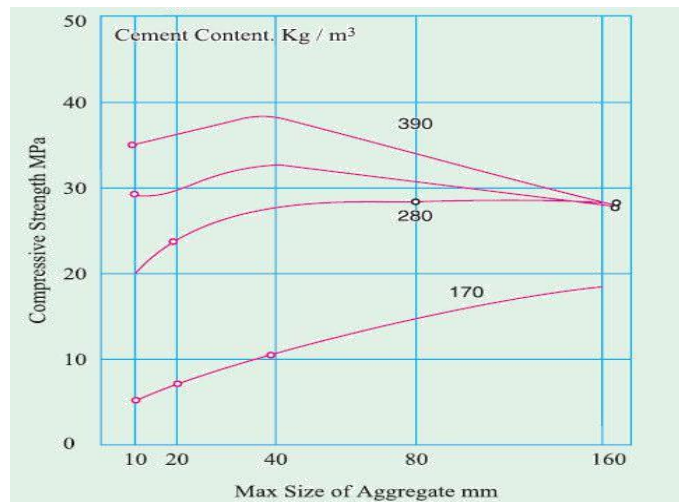
## Effect of Maximum size of Aggregate on Strength

At one time it was thought that the use of larger size aggregate leads to higher strength. This was due to the fact that the larger the aggregate the lower is the total surface area and, therefore, the lower is the requirement of water for the given workability.

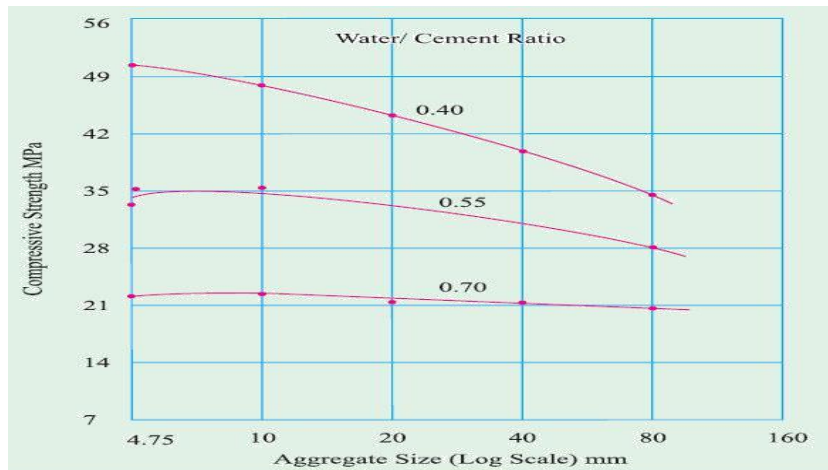
For this reason, a lower water/cement ratio can be used which will result in higher strength. However, later it was found that the use of larger size aggregate did not contribute to higher strength as expected from the theoretical considerations due to the following reasons.

The larger maximum size aggregate gives lower surface area for developments of gel bonds which is responsible for the lower strength of the concrete. Secondly bigger aggregate size causes a more heterogeneity in the concrete which will prevent the uniform distribution of load when stressed. When large size aggregate is used, due to internal bleeding, the transition zone will become much weaker due to the development of micro cracks which result in lower compressive strength.

Generally, high strength concrete or rich concrete is adversely affected by the use of large size aggregate. But in lean mixes or weaker concrete the influence of size of the aggregate gets reduced. It is interesting to note that in lean mixes larger aggregate gives highest strength while in rich mixes it is the smaller aggregate which yields higher strength. Fig. shows the influence of maximum size of aggregate on compressive strength of concrete.



The following Fig. depicts the influence of size of aggregate on compressive strength of concrete for different w/ c ratio.



## Relation between Compressive and Tensile Strength

In reinforced concrete construction the strength of the concrete in compression is only taken into consideration. The tensile strength of concrete is generally not taken into consideration. But the design of concrete pavement slabs is often based on the flexural strength of concrete. Therefore, it is necessary to assess the flexural strength of concrete either from the compressive strength or independently.

The tensile strength of concrete, as compared to its compressive strength, is more sensitive to improper curing. This may be due to the inferior quality of gel formation as a result of improper curing and also due to the fact that improperly cured concrete may suffer from more shrinkage cracks.

The Indian Standard IS = 456 of 2000 gives the following relationship between the compressive strength and flexural strength

$$\text{Flexural Strength} = 0.7 f_{ck}$$

Where  $f_{ck}$  is the characteristic compressive strength of concrete in  $\text{N/mm}^2$



It is seen that strength of concrete in compression and tension (both direct tension and flexural tension) are closely related, but the relationship is not of the type of direct proportionality. The ratio of the two strengths depends on general level of strength of concrete. In other words, for higher compressive strength concrete shows higher tensile strength, but the rate of increase of tensile strength is of decreasing order. The type of coarse aggregate influences this relationship. Crushed aggregate gives relatively higher flexural strength than compressive strength. This is attributed to the improved bond strength between cement paste and aggregate particles.

## **Curing of Concrete**

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.

In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water cement ratio of 0.38 would satisfy the requirement of water for hydration and at the same time no capillary cavities would be left. However, it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

## **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.,

## **Membrane Curing**

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. It has been pointed out earlier that curing does not mean only application of water, it means also creation of conditions for promotion of uninterrupted and progressive hydration.

It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane which will effectively seal off the evaporation of water from concrete. It is found that the application of membrane or a sealing compound, after a short spell of water curing for one or two days is sometimes beneficial sometimes, concrete is placed in some inaccessible, difficult or far off places.

## **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.

## **Steam curing at ordinary pressure**

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

## **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".

## **Finishing**

Finishing operation is the last operation in making concrete. Finishing in real sense 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.

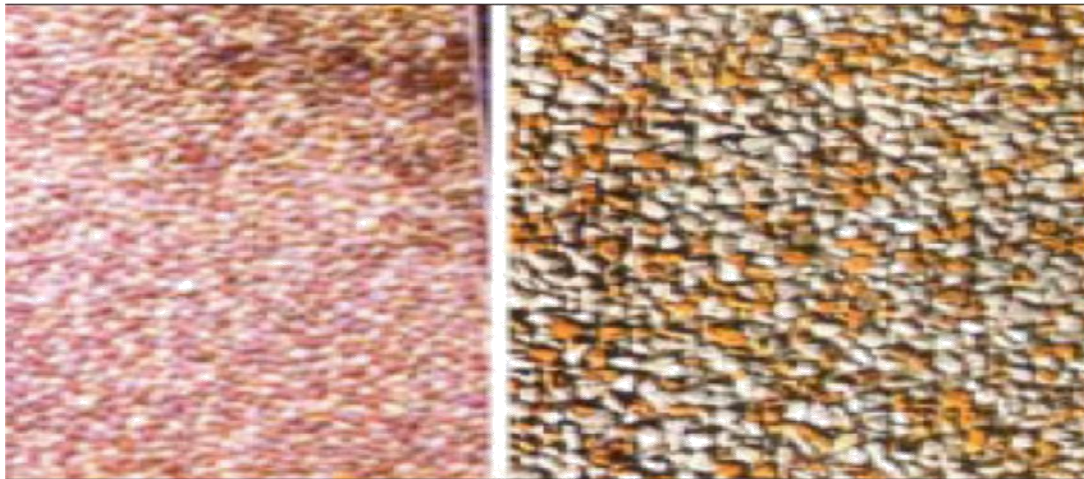
In recent years there has been a growing tendency to develop and use various surface treatments which permit concrete structures to proudly proclaim its nature instead of covering itself with an expensive veneer.

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.



Mechanical trowel for finishing factory floor.



Exposed aggregate finish

## **TESTING OF HARDENED CONCRETE**

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regard to both strength and durability. One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength.

The results of the test on hardened concrete even if they are known late, help to reveal the quality of concrete and enable adjustments to be made in the production of further concretes. Tests are made by casting cubes or cylinder from the representative concrete or cores cut from the actual concrete. It is to be remembered that standard compression test specimens give a measure of the potential strength of the concrete, and not of the strength of the concrete in structure. Knowledge of the strength of concrete in structure can not be directly obtained from tests on separately made specimens.

### **Compression Test**

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on specimens cubical or cylindrical in shape. The cube specimen is of the size 15 x 15 x 15 cm.

### **Moulds**

Metal moulds, preferably steel or cast iron, thick enough to prevent distortion are required

### **Curing**

The test specimens are stored in place free from vibration, in moist air of at least 90% relative humidity and at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$  for 24 hours  $\pm 1/2$  hour from the time of addition of water to the dry ingredients. After this period, the specimens are marked and removed from the moulds and unless required for test within 24 hours, immediately submerged in clean fresh water or saturated lime solution and kept there until taken out just prior to test. The water or solution in which the specimens are submerged, are renewed every seven days and are maintained at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$ . The specimens are not to be allowed to become dry at any time until they have been tested

### **Failure of Compression Specimen**

Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson's ratio effect. The steel plates do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the

adjacent steel plates of the testing machine. It has been found that the lateral strain in the steel platens is only 0.4 of the lateral strain in the concrete. Due to this the platen restrains the lateral expansion of the concrete in the parts of the specimen near its end. The degree of restraint exercised depends on the friction actually developed. When the friction is eliminated by applying grease, graphite or paraffin wax to the bearing surfaces the specimen exhibits a larger lateral expansion and eventually splits along its full length.

With friction acting i.e., under normal conditions of test, the elements within the specimen is subjected to a shearing stress as well as compression. The magnitude of the shear stress decreases and the lateral expansion increases in distance from the platen. But if the specimen is longer than about 1.7 d, a part of it will be free from the restraining effect of the platen. Specimens, whose length is less than 1.5 d, show a considerably higher strength than those with a greater length.

### **Comparison between Cube and Cylinder Strength**

It is difficult to say whether cube test gives more realistic strength properties of concrete or cylinder gives a better picture about the strength of concrete. However, it can be said that the cylinder is less affected by the end restrains caused by platens and hence it seems to give more uniform results than cube. Therefore, the use of cylinder is becoming more popular, particularly in the research laboratories.

Cylinders are cast and tested in the same position, whereas cubes are cast in one direction and tested from the other direction. In actual structures in the field, the casting and loading is similar to that of the cylinder and not like the cube. As such, cylinder simulates the condition of the actual structural member in the field in respect of direction of load. The points in favour of the cube specimen are that the shape of the cube resembles the shape of the structural members often met with on the ground. The cube does not require capping, whereas cylinder requires capping. The capping material used in case cylinder may influence to some extent the strength of the cylinder.

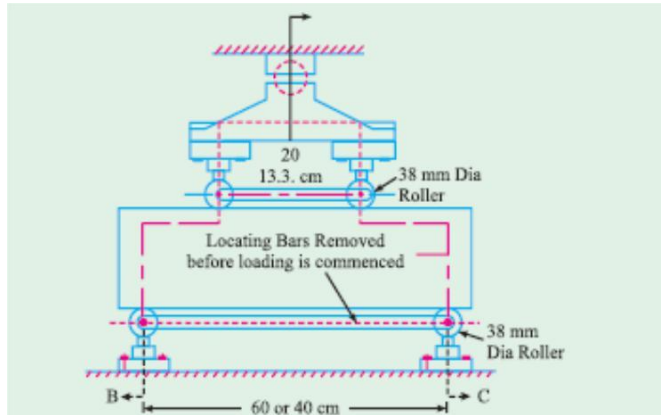
### **The Flexural Strength of Concrete**

Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons. Therefore, the knowledge of tensile strength of concrete is of importance.

.Stresses due to volume changes alone may be high. The longitudinal tensile stress in the bottom of the pavement, caused by restraint and temperature warping, frequently amounts to as much as 2.5 MPa at certain periods of the year and the corresponding stress in the transverse direction is approximately 0.9 MPa. These stresses are additive to those produced by wheel loads on unsupported portions of the slab.

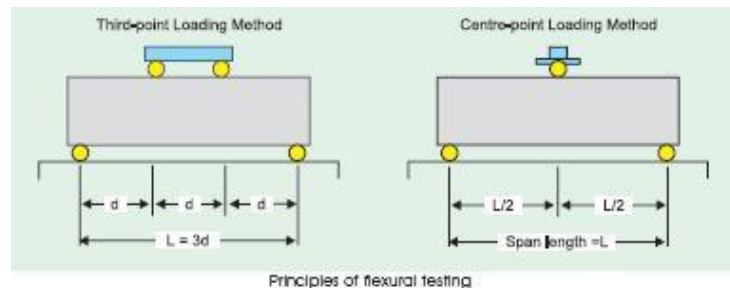
## Determination of Tensile Strength

Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the “pull” applied to the concrete.



While a number of investigations involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete. The value of the modulus of rupture (extreme fibre stress in bending) depends on the dimension of the beam and manner of loading. The systems of loading used in finding out the flexural tension are central point loading and third point loading.

In the central point loading, maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two point loading will yield a lower value of the modulus of rupture than the centre point loading.



The standard size of the specimens are 15 x 15 x 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 20 mm, specimens 10 x 10 x 50 cm may be used. The mould should be of metal, preferably steel or cast iron and the metal should be of sufficient thickness to prevent spreading or warping. The mould should be constructed with the longer dimension horizontal and in such a manner as to facilitate the removal of the moulded specimens without damage. The tamping bar should be a steel bar weighing 2 kg, 40 cm long and should have a ramming face 25 mm square.

The bed of the testing machine should be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported, and these rollers should be so mounted that the distance from centre to centre is 60 mm for 15 cm specimen or 40 cm for 10.0 cm specimens. The load is applied through two similar rollers mounted at the third points of the supporting span, which is, spaced at 20 or 13.3 cm centre to centre. The load is divided equally between the two loading rollers, and all rollers are mounted in such a manner that the load is applied axially and without subjecting specimen to any torsional stresses or restrains.

## **Procedure**

Test specimens are stored in water at a temperature of 24° to 30°C for 48 hours before testing. They are tested immediately on removal from the water whilst they are still in a wet condition. The dimensions of each specimen should be noted before testing. No preparation of the surfaces is required.

## **Placing the Specimen in the Testing Machine**

The bearing surfaces of the supporting and loading rollers are wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers. The specimen is then placed in the machine in such a manner that the load is applied to the uppermost surface as cast in the mould, along two lines spaced 20.0 or 13.3 cm apart. The axis of the specimen is carefully aligned with the axis of the loading device. No packing is used between the bearing surfaces of the specimen and the rollers.

The load is applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 0.7 kg/sq cm/min that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens. The load is increased until the specimen fails, and the maximum load applied to the specimen during the test is recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure is noted.

The third problem is the stresses induced due to the grips. There is a tendency for the specimen to break near the ends. This problem is always overcome by reducing the section of the central portion of the test specimen. The method in which steel plates are glued with the epoxies to the ends of test specimen, eliminates stresses due to gripping, but offers no solution for the eccentricity problem. All direct tension test methods require expensive universal testing machine. This explains why these tests are not used on a routine basis and are not yet standardized.



splitting tensile test

## NDT METHODS (NON DESTRUCTIVE TESTING METHODS)

### Rebound Hammer

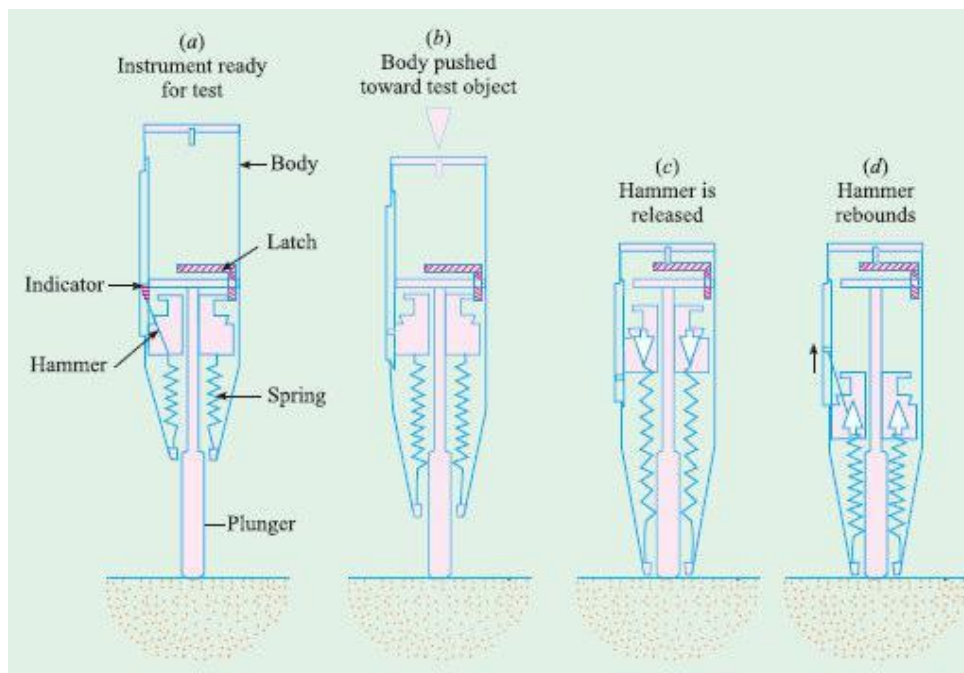
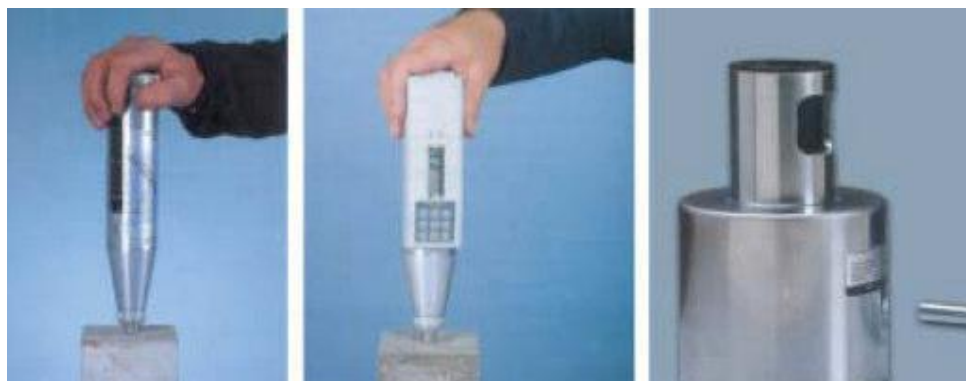


Fig: Schematic cross section of rebound hammer showing operating principle





## Rebound Number and Strength of Concrete

Investigations have shown that there is a general correlation between compressive strength of concrete and rebound number; however, there is a wide degree of disagreement among various research workers regarding the accuracy of estimation of strength from rebound readings. The variation of strength of a properly calibrated hammer may lie between  $\pm 15\%$  and  $\pm 20\%$ . The relationship between flexural strength and rebound number is found to be similar to those obtained for compressive strength, except that the scatter of the results is greater.

## Penetration Techniques

The measurement of hardness by probing techniques was first reported during 1954. Two techniques were used. In one case, a hammer known as, “Simbi” was used to perforate concrete and the depth of borehole was correlated to compressive strength of concrete cubes. In the other technique, the probing of concrete was achieved by blasting with spit pins and the depth of penetration of the pins was correlated with compressive strength of concrete.

## Pullout test

A pullout test measures the force required to pull out from the concrete a specially shaped rod whose enlarged end has been cast into that concrete. The stronger the concrete, the more is the force required to pullout. The ideal way to use pullout test in the field would be to incorporate assemblies in the structure. These standard specimens could then be pulled out at any point of time. The force required denotes the strength of concrete. Another way to use pullout test in the field would be to cast one or two large blocks of concrete incorporating pullout assemblies. Pullout test could then be performed to assess the strength of concrete.

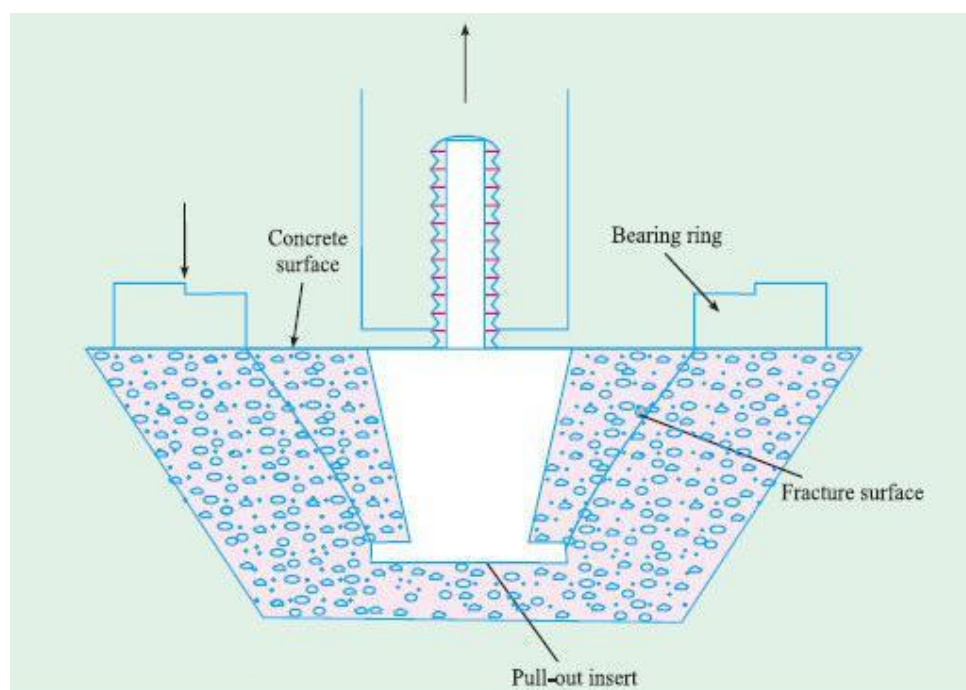


Fig: Diagrammatic representation of the pull-out test

## **Dynamic or Vibration Methods**

This is the important non-destructive method used in testing concrete strength and other properties. The fundamental principle on which the dynamic or vibration methods are based is velocity of sound through a material. A mathematical relationship could be established between the velocity of sound through specimen and its resonant frequency and the relationships of these two to the modulus of elasticity of the material. The relationships which are derived for solid mediums considered to be homogeneous, isotropic and perfectly elastic, but they may be applied to heterogeneous materials like concrete.

## **Pulse Velocity Method**

This can be sub-divided into two parts:

(a ) Mechanical sonic pulse velocity method, which involves measurement of the time of travel of longitudinal or compressional waves generated by a single impact hammer blow or repeated blows.

(b) Ultrasonic Pulse Velocity Method, which involves measurement of the time of travel of electronically generated mechanical pulses through the concrete.

Out of these two, the ultrasonic pulse method has gained considerable popularity all over the world. When mechanical impulses are applied to a solid mass, three different kinds of waves are generated. These are generally known as longitudinal waves, shear waves and surface waves. These three waves travel at different speeds. The longitudinal or compressional waves travel about twice as fast as the other two types. The shear or transverse waves are not so fast, the surface waves are the slowest.

### **Techniques of Measuring Pulse Velocity through Concrete**

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

(a) Direct transmission.

(b) Indirect transmission.

(c) Surface transmission.

### **Factors Affecting the Measurement of Pulse Velocity**

The measurement of pulse velocity is affected by a number of factors regardless of the properties of concrete.

**1. Smoothness of contact surface under test:** It is important to maintain good acoustical contact between the surface of concrete and the face of each transducer. Generally this does not pose any problem because in normal testing sufficient cast surfaces are available for good contact. However, when it is necessary to hold the transducer against an unmoulded surface, for example, the top surface of a test cylinder, it is desirable to smoothen the surface by the use of a carborundum stone and the transducers should be held tightly against

the concrete surface. In addition, the use of a coupling medium such as a thin film of oil, soap, jelly, or kaolin glycerol paste should be used.

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

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

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

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

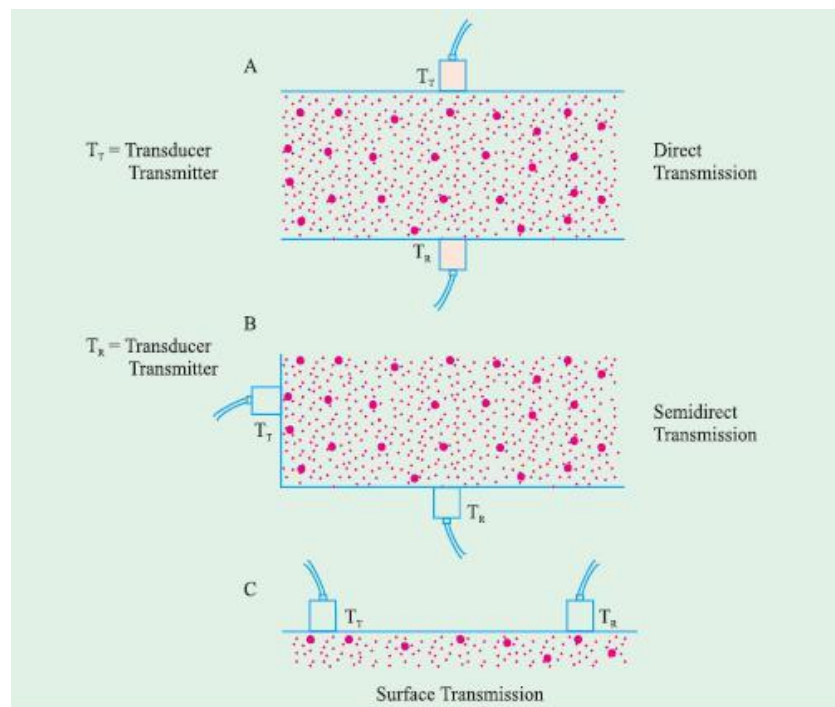


Fig: Method of measuring Pulse velocity through concrete

**Accuracy of Measurement.** It is generally agreed that the ultrasonic concrete tester measures the transit time through small specimens with an accuracy of 0.1 microseconds; for the specimens of the same length, the accuracy of measurement for the sonoscope and the PUNDIT is of the order of 0.5 microseconds. Thus, the former instrument is ideally suited for controlled laboratory studies, whereas the latter are best suited for field investigations where the path lengths are longer.

### **Applications**

The pulse velocity methods have been used to evaluate concrete structures and attempts have been made to correlate the pulse velocity with strength and other properties of concrete.

The various applications of the pulse velocity methods are described below:

**Establishing uniformity of concrete:** For establishing the uniformity of concrete, the ultrasonic concrete tester is an ideal tool for laboratory specimens, whereas the sonoscope and PUNDIT provide an excellent means for both laboratory and field studies. **Establishing acceptance criteria:** Generally, high pulse velocity reading in concrete are indicative of concrete of good quality.

**Determination of pulse modulus of elasticity:** Theoretically, the values of the pulse modulus of elasticity calculated from the readings obtained with the sonoscope or the ultrasonic concrete tester should be the same as those obtained with resonant frequency techniques. However, this has not been found to be so. For this reason and also because the modulus of elasticity depends upon density and Poisson's ratio, most researchers have attempted to use pulse velocity itself as a criterion of the quality of concrete without attempting to calculate moduli there from.

**Estimation of strength of concrete:** Various researchers have attempted to correlate compressive and flexural strength of concrete with pulse velocity.

**Determination of setting characteristics of concrete:** The determination of the rate of setting of concrete by means of the sonoscope has been widely used.

**Studies on durability of concrete:** Durability of concrete under freeze-thaw action and the aggressive environments such as sulphate attack and acidic waters, have been studied by various investigators using the pulse velocity technique to assess damage.

**Pulse velocity techniques** have been successfully used for the measurement and detection of cracks. The basic principle of crack detection is that, if the crack is of appreciable width and considerable depth, perpendicular to the test path, no signal will be received at the receiving transducer. If the depth of the crack is small, compared to the distance between the transducers, the pulse will pass around the end of the crack and the signal is received at the transducer. However, in doing so, it would have travelled a distance longer than the straight line path upon

which pulse velocity computations are made. The difference in the pulse velocity is then used to estimate the path length and hence crack depth.

### **Combined Methods**

One of the most important objectives of non-destructive methods of testing of concrete is to estimate the compressive strength of concrete in structure. Use of any one method may not give reliable results. Using more than one method at the same time has been found to give reliable results regarding the strength of a structure. Most popular combination was found to be the ultrasonic pulse velocity method in conjunction with the hardness measurement techniques, and Rebound Hammer method.

### **Radioactive Methods**

The use of X-rays and gamma-rays as non-destructive method for testing properties of concrete is relatively new. X-ray and gamma-rays both components of the high energy region on the electromagnetic spectrum penetrate concrete but undergo attenuation in the process. The degree of attenuation depends on the kind of matter traversed, its thickness, and the wavelength of the radiation. The intensity of the incident gamma-rays and the emerging gamma-rays after passing through the specimens are measured. These two values are made use of for calculating the density of structural concrete members. Gamma-rays transmission method has been used to measure the thickness of concrete slabs of known density. Gamma radiation source of known intensity is made to pass and penetrate through the concrete. The intensity at the other face is measured. From this thickness of the concrete is calculated.

### **Nuclear Methods**

Use of nuclear methods for non-destructive measurement of some properties of concrete is of recent origin. Two principal techniques have been reported, namely neutron scattering methods for determining the moisture content of concrete and neutron activation analysis for the determination of cement content. These methods are not suitable for finding out the strength of concrete.

### **Magnetic Methods**

Battery operated magnetic devices that can measure the depth of reinforcement cover in concrete and detect the position of reinforcement bars are now available. The apparatus is known as cover meter. This can be used for measuring the cover given in the lightly reinforced sections.

### **Electrical Methods**

Recently some electrical methods have been employed for determining the moisture content of hardened concrete, tracing of moisture permeation through concrete and determining the thickness of concrete pavements. The accurate determination of the moisture content of hardened concrete is required in connection with creep, shrinkage and thermal conductivity studies. The fact that dielectric properties of hardened concrete change with changes in moisture content is made use of in this method.

Electrical resistivity methods have been used to find out the thickness of concrete pavements. The method is based on the principle that the material offers resistance to the passage of an electric current.