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Concrete testing and Diagnosing Kit

10
CHAPTER

Testing of Hardened Concrete

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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. The test methods should be simple, direct and convenient to apply.

One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength. As the hardening of the concrete takes time, one will not come to know, the actual strength of concrete for some time. This is an inherent disadvantage in conventional test. But, if strength of concrete is to be known at an early period, accelerated strength test can be carried out to predict 28 days strength. But mostly when correct materials are used and careful steps are taken at every stage of the work, concretes *normally give the required strength. The tests also have a deterring effect on those responsible for construction work. The results of the test on hardened concrete, even if they are known late, helps 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.

Cube beam and cylinder moulding

The compression test is carried out on specimens cubical or cylindrical in shape. Prism is also sometimes used, but it is not common in our country. Sometimes, the compression strength of concrete is determined using parts of a beam tested in flexure. The end parts of beam are left intact after failure in flexure and, because the beam is usually of square cross section, this part of the beam could be used to find out the compressive strength.

The cube specimen is of the size 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 20 mm, 10 cm size cubes may also be used as an alternative. Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in diameter and 30 cm long. Smaller test specimens may be used but a ratio of the diameter of the specimen to maximum size of aggregate, not less than 3 to 1 is maintained.

Moulds

Vibrating table for cubes

Metal moulds, preferably steel or cast iron, thick enough to prevent distortion are required. They are made in such a manner as to facilitate the removal of the moulded specimen without damage and are so machined that, when it is assembled ready for use, the dimensions and internal faces are required to be accurate within the following limits.

The height of the mould and the distance between the opposite faces are of the specified size ± 0.2 mm. The angle between adjacent internal faces and between internal faces and top and bottom planes of the mould is required to be 90° ± 0.5°. The interior faces of the mould, are plane surfaces with a permissible variation of 0.03 mm. Each mould is provided with a metal base plate having a plane surface. The base plate is of such dimensions as to support the mould during the filling without leakage and it is preferably attached to the mould by springs or screws. The parts of the mould, when assembled, are positively and rigidly held together, and suitable methods of ensuring this, both during the filling and on subsequent handling of the filled mould, are required to be provided.

In assembling the mould for use, the joints between the sections of the mould are thinly coated with mould oil and a similar coating of mould oil is applied between the contact surface of the bottom of the mould and the base plate in order to ensure that no water escapes during the filling. The interior surfaces of the assembled mould is also required to be thinly coated with mould oil to prevent adhesion of concrete.

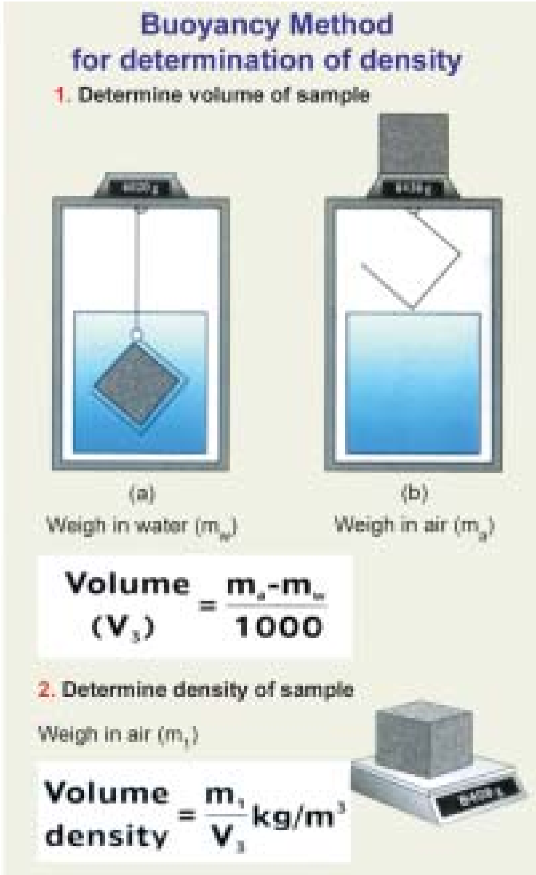
The cylindrical mould is required to be of metal which shall be not less than 3 mm thick. Each mould is capable of being opened longitudinally to facilitate removal of the specimen and is provided with means of keeping it closed while in use. Care should be taken so that the ends are not departed from a plane surface, perpendicular to the axis of the mould, by more than 0.05 mm. When assembled ready for use the mean internal diameter of the mould should be 15.0 cm ± 0.2 mm. and in no direction the internal diameter be less than 14.95 cm. or more than 15.05 cm. The height maintained is 30.0 cm ± 0.1 mm. Each mould is provided with a metal base plate, and with a capping plate of glass or orther suitable material. The base plate and the capping plate are required to be at least 6.5 mm thick and such that they do not depart from a plane surface by more than 0.02 mm. The base plate supports the mould during filling without leakage and is rigidly attached to the mould. The mould and base plate are coated with a thin film of mould oil before use, in order to prevent adhesion of concrete.

A steel bar 16 mm in diameter, 0.6 m long and bullet pointed at the lower end serves as a tamping bar.

Compacting

The test cube specimens are made as soon as practicable after mixing and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete is filled into the mould in layers approximately 5 cm deep. In placing each

Buoyancy Balance



scoopful of concrete, the scoop is required to be moved around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould. Each layer is compacted either by hand or by vibration. After the top layer has been compacted the surface of the concrete is brought to the finished level with the top of the mould, using a trowel. The top is covered with a glass or metal plate to prevent evaporation.

Compacting by Hand

When compacting by hand, the standard tamping bar is used and the strokes of the bar are distributed in a uniform manner over the cross-section of the mould. The number of strokes per layer required to produce the specified conditions vary according to the type of concrete. For cubical specimens, in no case should the concrete be subject to less than 35 strokes per layer for 15 cm or 25 strokes per layer for 10 cm cubes. For cylindrical specimens, the number of strokes are not less than thirty per layer. The strokes penetrate into the underlying layer and the bottom layer is rodded throughout its depth. Where voids are left by the tamping bar, the sides of the mould are tapped to close the voids.

Compacting by Vibration

When compacting by vibration, each layer is vibrated by means of an electric or pneumatic hammer or vibrator or by means of a suitable vibrating table until the specified condition is attained. The mode and quantum of vibration of the laboratory specimen shall be as nearly the same as those adopted in actual concreting operations. Care must be taken while compacting high slump concrete which are generally placed by pumping. If care its not taken severe segregation takes place in the mould, which results in low strength when cubes are crushed. The cube crushing strength does not represent the strength of the concrete.

Capping Specimens

Capping is applicable to cylindrical specimen. The ends of all cylindrical test specimens that are not plane within 0.05 mm are capped. The capped surfaces are not departed from a plane by more than 0.05 mm and shall be nearly at right angles to the axis of the specimens. The planeness of the cap is required to be checked by means of a straight edge and feeler gauge, making a minimum of three measurements on different diameters. Caps are made as thin as practicable and care should be taken so that flaw or fracture does not take place, when the specimen is tested. Capping can be done on completion of casting or a few hours prior to testing of specimen. Capping is required to be carried out according to one of the following methods:

(a) ***Neat Cement:*** *The test cylinders may be capped with a thin layer of stiff, neat Portland cement paste after the concrete has set in the moulds: Capping is done after about 4 hours of casting so that concrete in the cylinder undergoes plastic shrinkage and subsides fully. The cap is formed by means of a glass plate not less than 6.5 mm in thickness or a machined metal plate not less than 13 mm in thickness and having a minimum surface dimension at least 25 mm larger than the diameter of the mould. It is worked on the cement paste until its lower surface rests on the top of the mould. The cement for capping is mixed to a stiff paste for about 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of paste to the capping plate is avoided by coating the plate with a thin coat of oil or grease.*

(b) ***Cement Mortar:*** *On completion of casting cylinder, a mortar is gauged using cement similar to that used in the concrete and sand which passes IS Sieve 300 but is retained on IS Sieve 150. The mortar should have a water/cement ratio not higher than that of the concrete of which the specimen is made, and should be of a stiff consistency. If an excessively wet mix of concrete is being tested, any free water which has collected on the surface of the specimen should be removed with a sponge, blotting paper or other suitable absorbant material before the cap is formed. The mortar is then applied firmly and compacted with a trowel to a slightly convex surface above the edge of the mould, after which the capping plate is pressed down on the cap with a rotary motion until it makes complete contact with the rim of the mould. The plate should be left in position until the specimen is removed from the mould.*

(c) ***Sulphur:*** *Just prior to testing, the cylindrical specimens are capped with a sulphur mixture consisting of 1 part of sulphur to 2 or 3 parts of inert filler, such as fire-clay. The specimens are securely held in a special jig so that the caps formed have a true plane surface. Care has to be taken to ensure that the sulphur compound is not over-heated as it will not then develop the required compressive strength. Sulphur caps are allowed to harden for at least 2 hours before applying the load.*

Compression testing machine

(*d*) **Hard Plaster:** *Just prior to testing, specimens are capped with hard plaster having a compressive strength of at least 42 MPa cm in an hour. Such plasters are generally available as proprietary material. The caps can be formed by means of a glass plate not less than 13 mm in thickness, having a minimum surface dimension at lest 25 mm larger than the diameter of the mould. The glass plate is lightly coated with oil to avoid sticking. Ordinary plaster of paris will not serve the purpose of capping material due to its low compressive strength.*

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° ± 2°C for 24 hours ± $^1/_2$ 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° ± 2°C. The specimens are not to be allowed to become dry at any time until they have been tested.

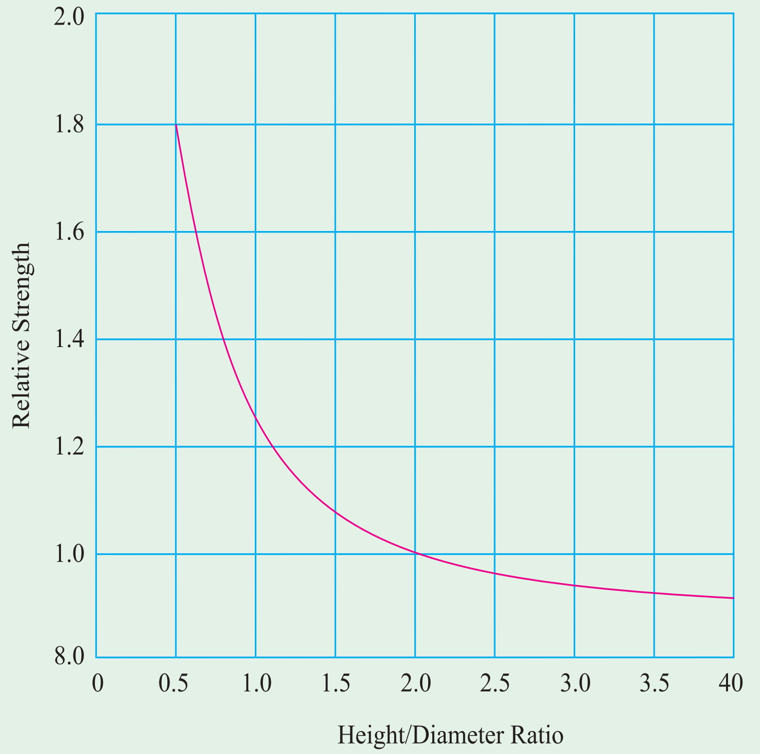
Making and Curing Compression Test Specimen in the Field

The test specimens are stored on the site at a place free from vibration, under damp matting, sacks or other similar material for 24 hours ± $^1/_2$ hour from the time of addition of water to the other ingredients. The temperature of the place of storage should be within the range of 22° to 32°C. After the period of 24 hours, they should be marked for later identification removed from the moulds and unless required for testing within 24 hours, stored in clean water at a temperature of 24° to 30°C until they are transported to the testing laboratory. They should be sent to the testing laboratory well packed in damp sand, damp sacks, or other suitable material so as to arrive there in a damp condition not less than 24 hours before the time of test. On arrival at the testing laboratory, the specimens are stored in water at a temperature of 27° ± 2°C until the time of test. Records of the daily maximum and minimum temperature should be kept both during the period the specimens remain on the site and in the laboratory particularly in cold weather regions.

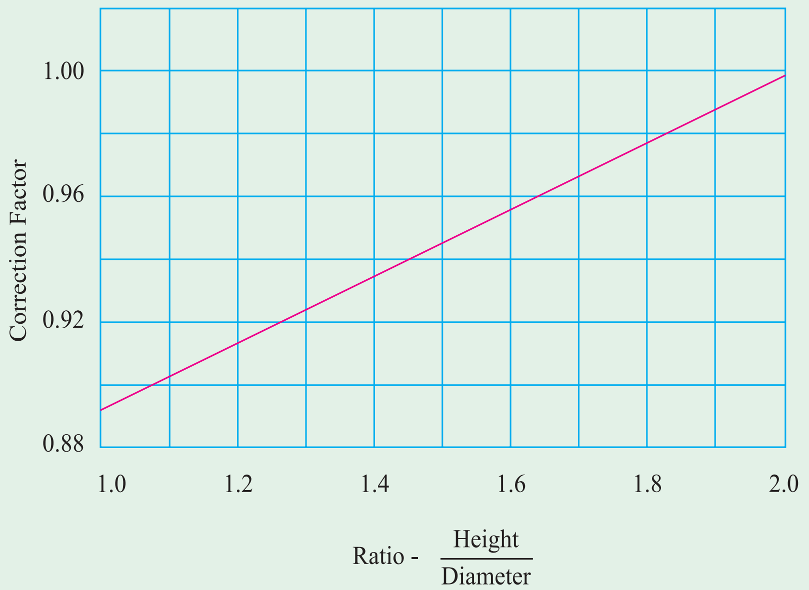
Failure of Compression Specimen

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 platens 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 platens 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 ths 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. As a result of the restraint, in a specimen tested to destruction there is a relatively undamaged cone of



height equal to $\frac{\sqrt{3}}{2}$ d (where d is the lateral dimension of the specimen).[10.1] *But if the specimen is longer than about 1.7 d, a part it of 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. (See Fig. 10.1).*



Effect of the Height/Diameter Ratio on Strength

Normally, height of the cylinder "h" is made twice the diameter "d", but sometimes, particularly, when the core is cut from the road pavements or airfield pavements or foundations concrete, it is not possible to keep the heigh/diameter ratio of 2:1. The diameter of the core depends upon the cutting tool, and the height of the core will depend upon the thickness of the concrete member. If the cut length of the core is too long. It can be trimmed to h/d ratio of 2 before testing. But with too short a core, it is necessary to estimate the strength of the same concrete, as if it had been determined on a specimen with h/d ratio equal to 2.

Fig. 10.2 shows the correction factor for height/diameter ratio of a core (IS 516.1959).

Murdock and Kesler[10.2] found that correlation factor is not a constant one but depends on the strength level of concrete. High strength concrete is less affected than the low strength concrete. Figure 10.3 shows the influence of h/d ratio on the strength of cylinder for different strength levels.

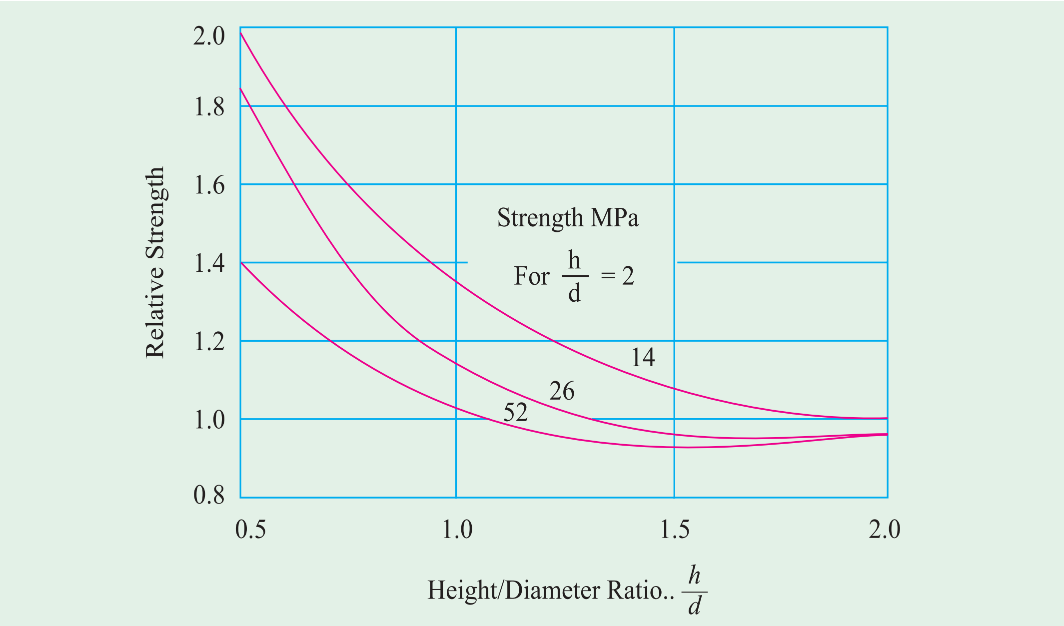


Figure 10.1 shows the general pattern of influence of h/d ratio on the strength of cylinder.

It is interesting to note that the restraining effect of the platens of the testing machine extends over the entire height of the cube but leaves unaffected a part of test cylinder because of greater height. It is, therefore, the strength of the cube made from identical concrete will be different from the strength of the cylinder. Normally strength of the cylinder is taken as 0.8 times the strength of the cube, but experiments have shown that there is no unique relationship between the strength of cube and strength of cylinder. It was seen that the strength relation varies with the level of the strength of concrete. For higher strength, the difference between the strength of cube and cylinder is becoming narrow. For 100 MPa concrete the ratio may become nearly 1.00. Table 10.1 shows the strength pattern of cubes and cylinders.

Table 10.1. Strength of Cubes and Cylinders

Compressive Strength		Ratio of strengths cylinder/ cube	Difference of strength (cube-cylinders)
Cube MPa	Cylinder MPa		MPa
9.0	7.0	0.77	2
16.0	12.0	0.77	4
20.0	16.0	0.76	4
25.0	20.0	0.81	5
28.0	25.0	0.87	3
30.0	27.0	0.91	3
30.0	28.0	3.91	2
36.0	32.0	3.89	4
37.0	35.0	0.94	2
43.0	37.0	0.87	6
45.0	42.0	0.92	3
49.0	45.0	0.91	4
54.0	51.0	0.96	3

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

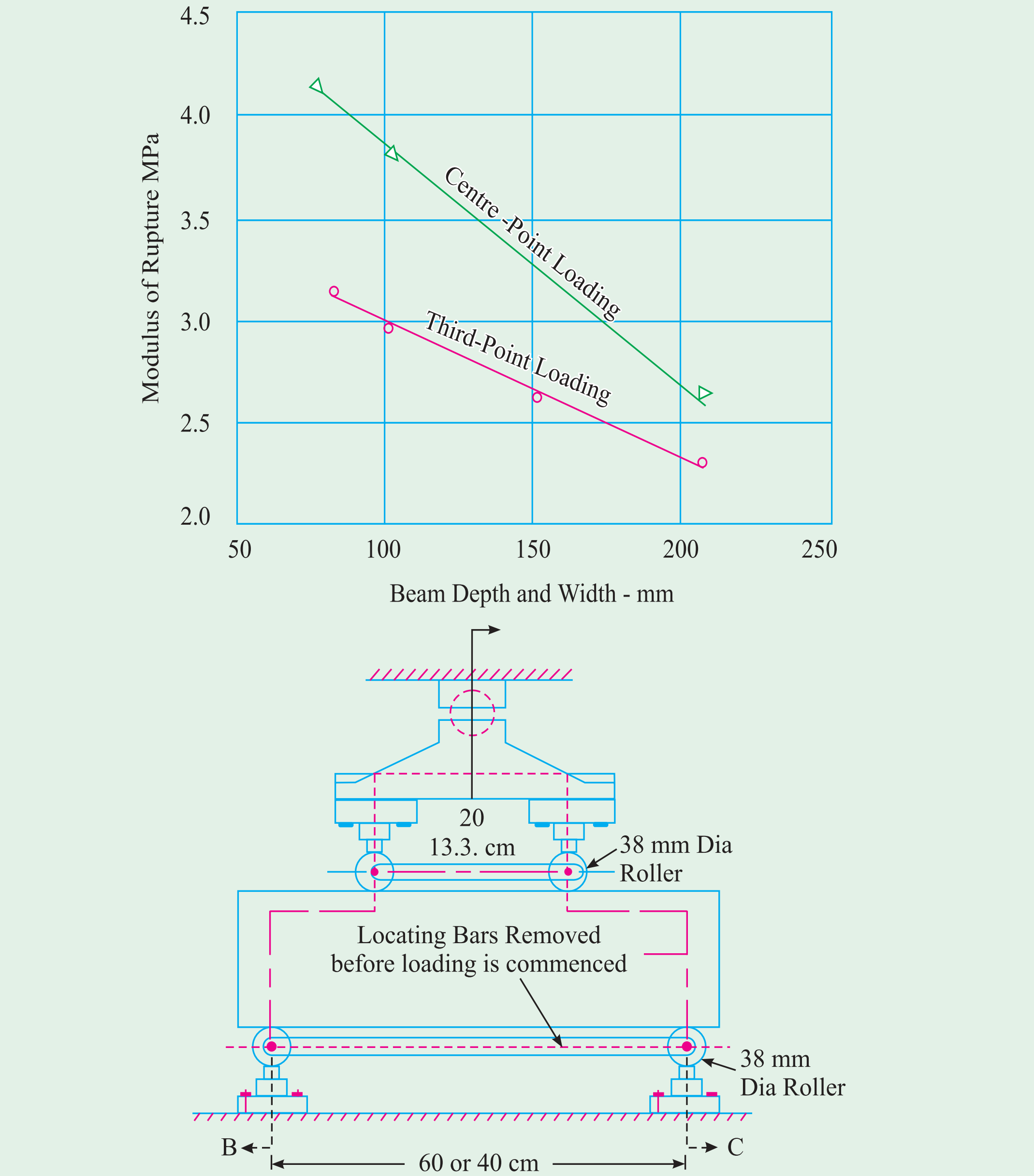
Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete 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.

A concrete road slab is called upon to resist tensile stresses from two principal sources– wheel loads and volume change in the concrete. Wheel loads may cause high tensile stresses *due to bending, when there is an inadequate subgrade support. Volume changes, resulting from changes in temperature and moisture, may produce tensile stresses, due to warping and due to the movement of the slab along the subgrade.*

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

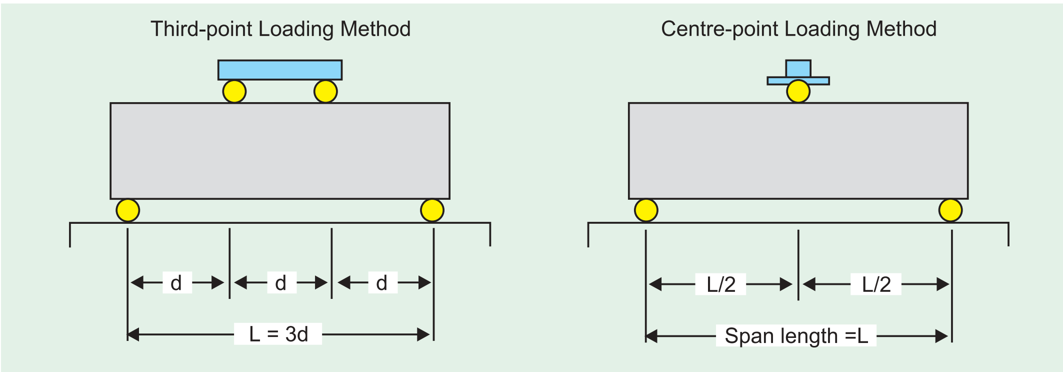
Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied



Flexural testing of concrete beam mould

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. Figure 10.4 shows the modulus of rupture of beams of different sizes subjected to centre point and third point loading. I.S. 516-1959, specifies two point loading. The details of the specimen and procedure are described in the succeeding paragraphs.



Principles of flexural testing

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 testing machine may be of any reliable type of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible errors should not be greater that ± 0.5 per cent of the applied load where a high degree of accuracy is required and not greater than ± 1.5 per cent of the applied load for commercial type of use. 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, that 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. The loading set up is shown in Fig. 10.5.

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 flexural strength of the specimen is expressed as the modulus of rupture f_b *which if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05 MPa as follows:*

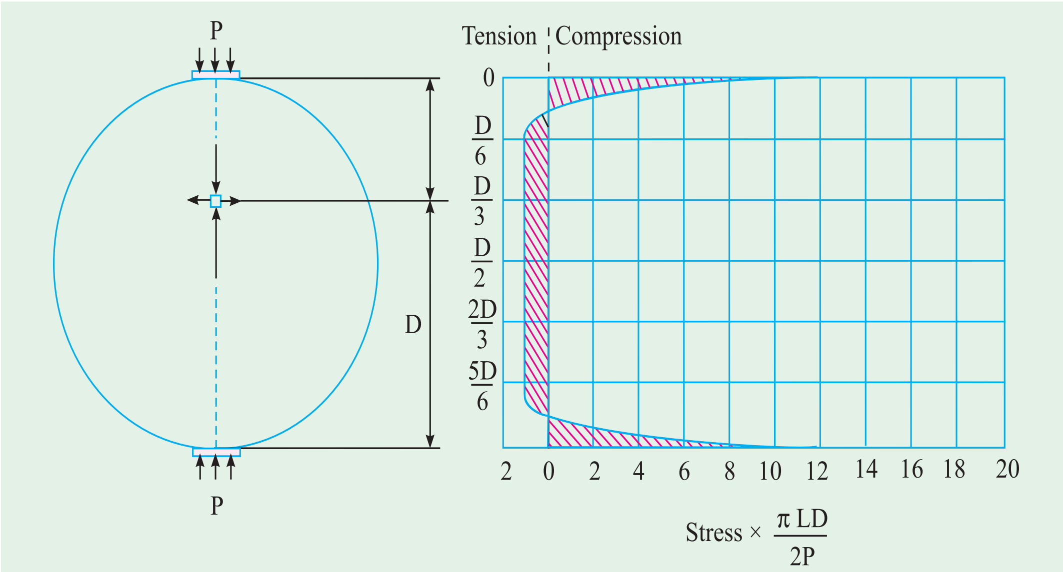
$$f_b = \frac{P \times l}{b \times d^2}$$

When 'a' is greater than 20.0 cm for 15.0 cm specimen or greater than 13.3 cm for a 10.0 cm specimen, or

$$f_b = \frac{3p \times a}{b \times d^2}$$

when 'a' is less than 20.0 cm but greater than 17.0 cm for 15.0 specimen, or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen where

b = measured width in cm of the specimen,



d = *measured depth in cm of the specimen at the point of failure,*

l = *length in cm of the span on which the specimen was supported, and*

p = *maximum load in kg applied to the specimen.*

If 'a' is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the results of the test be discarded.

As mentioned earlier, it is difficult to measure the tensile strength of concrete directly. Of late some methods have been used with the help of epoxy bonded end pieces to facilitate direct pulling. Attempts have also been made to find out direct tensile strength of concrete by making briquette of figure 8 shape for direct pulling but this method was presenting some difficulty with grip and introduction of secondary stresses while being pulled.

Splitting tensile test

Whatever may be the methods adopted for finding out the ultimate direct tensile strength, it is almost impossible to apply truly axial load. There is always some eccentricity present. The stresses are changed due to eccentricity of loading. These may introduce major error on the stresses developed regardless of specimen size and shape.

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 griping, 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 standardised.

Indirect Tension Test Methods

Cylinder Splitting Tension Test: This is also sometimes referred as, "Brazilian Test". This test was developed in Brazil in 1943. At about the same time this was also independently developed in Japan.

The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter. Figure 10.6 shows the test specimen and the stress pattern in the cylinder respectively.

When the load is applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of

$$\frac{2P}{\pi LD} \left[\frac{D^2}{r(D-r)} - 1\right]$$

and a horizontal stress of

$$\frac{2P}{\pi LD}$$

where, *P* is the compressive load on the cylinder

L is the length of cylinder

D is its diameter

and *r* and (*D* – *r*) are the distances of the elements from the two loads respectively.

The loading condition produces a high compressive stress immediately below the two generators to which the load is applied. But the larger portion corresponding to depth is subjected to a uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about 1/6 depth and the remaining 5/6 depth is subjected to tension.

In order to reduce the magnitude of the high compression stresses near the points of application of the load, narrow packing strips of suitable material such as plywood are placed between the specimen and loading platens of the testing machine. The packing strips should be soft enough to allow distribution of load over a reasonable area, yet narrow and thin enough to prevent large contact area. Normally, a plywood strip of 25 mm wide, 3 mm thick and 30 cm long is used.

The main advantage of this method is that the same type of specimen and the same testing machine as are used for the compression test can be employed for this test. That is why this test is gaining popularity. The splitting test is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believed to be closer to the true tensile strength of concrete, than the modulus of rupture. Splitting strength gives about 5 to 12% higher value than the direct tensile strength.

Ring Tension Test [10.17]

Another test for finding out the tensile strength of concrete is known as "Ring Tension Test". Briefly in this method, a hydrostatic pressure is applied radially against the inside periphery of 15 cm diameter, 4 mm thick and 4 mm high concrete ring specimen. The resulting tensile stress developed in the specimen are determined from the equations of the stress analysis of thick walled cylinders, as given below:

$$f_t = \frac{P_{i-}r_i^2}{r_0^2 - r_i^2}\left(1 - \frac{r_0^2}{r^2}\right)$$

where, f_t = *Tensile strength*

p_i = *Applied hydrostatic pressure*

r_i = *Internal radius*

r_0 = *External radius*

r = *Radius at point of failure*

Advantages of Ring Tension Test

The nature of the load application in this test is such that no clamping and misalignment stresses are introduced in the test specimen, a condition difficult to avoid in direct tests.

The entire volume of the ring is subjected to tensile stresses with the uniformly distributed maximum stress occurring along the entire periphery of the ring. This is never achieved in the flexural tests and even in the cylinder splitting test a compressive load acting on a diametral plane creates a uniform tensile stress over that plane only.

The magnitude of the radial compressive stress is quite small when compared with the tangential stress. This is a definite advantage over the splitting tension test in which the minimum compressive stresses occurring at the centre line of the splitting plane is about three times the corresponding tensile stress.

Limitations of Ring Tension Test

The drawbacks of this test are that here also, the derivation of equations used for the stress analysis is based upon Hook's Law of linear stress-strain proportionality. The ring tensile strengths obtained appear to be somewhat higher than the true tensile strength of concrete, the magnitude of the exact difference has yet to be firmly established.

Double Punch Test [10.16]

Yet another test to find out the indirect tensile strength of concrete is known as "Double Punch Test". In this test, a concrete cylinder is placed vertically between the loading plates of the compression test machine and compressed by the steel punches located concentrically on the top and bottom surfaces of the cylinder.

An ideal failure mechanism will consist of many simple tension cracks in radial direction and two cone shaped rupture surfaces directly under the loads. Two cone shapes move towards each other as a rigid body and displace the surrounding material horizontally sideways. The formulae for calculating the tensile strength has been calculated on the basis of limit analysis. The relation is :

$$f_t = \frac{Q}{(1.20\, bH - a^2)}$$

where, *a* = *radius of punch*
b = *radius of cylinder*
H = *height of the cylinder*
Q = *load at failure*

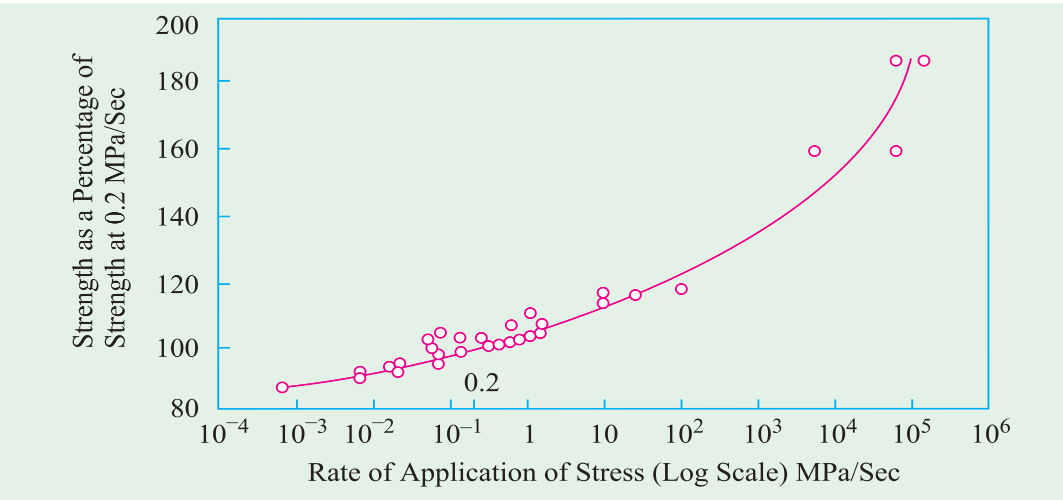
Factors influencing the strength results

It has already been pointed out that shape and size of specimen affects the strength results. If the strength of the 15 cm size cube is taken as standard, then the strength of 10 cm cube should be reduced by 10%. Strength of the cylinder of size 15 cm diameter and 30 cm long is taken as 0.8 of the strength of 15 cm cube. Where cubes larger than 15 cm are adopted, generally no modification to the strength is necessary unless otherwise specified.

The planeness of the end condition of specimen and capping material used for the cylinder affects the strength. The employment of lubricating material at the bearing surface of the sample affect the strength of concrete.

The effect of height to diameter ratio has already been discussed.

The rate of application of load has a considerable affect on the apparent strength of concrete; the lower the rate of application of load, the lower will be the recorded strength. The reason for this is probably the effect of creep. If the load is applied slowly, or in the application of load, if there is some time-lag, the specimen will undergo certain amount of creep which will increase the strain. The enhanced strain due to creep will be responsible for failure of the sample, at a lower value of stress applied. The Figure 10.7 shows the influence of rate of application of load on the compressive strength of concrete.



The state of moisture content of the specimen influences the observed strength to a great extent. If two cubes made from identical concrete, one is wet and another is dry, if tested at the same age, the dry cube gives higher strength than the wet cube. It is quite probable that the dry cube may have undergone drying shrinkage which will have ultimately caused some amount of drying shrinkage cracks and bond failures. From this simple reason it must give an impression that dry cube must give a lower value, but on the contrary the result is the other way. The probable explanation is that due to wetting, some sort of dilation of cement gel will take place by the adsorbed water. The forces of cohesion of the solid particles are then *decreased. Perhaps the decrease of strength on account of reduction of cohesion owing to the adsorbed water may be more than that of the loss of strength due to rupture of gel bonds on account of drying shrinkage.*

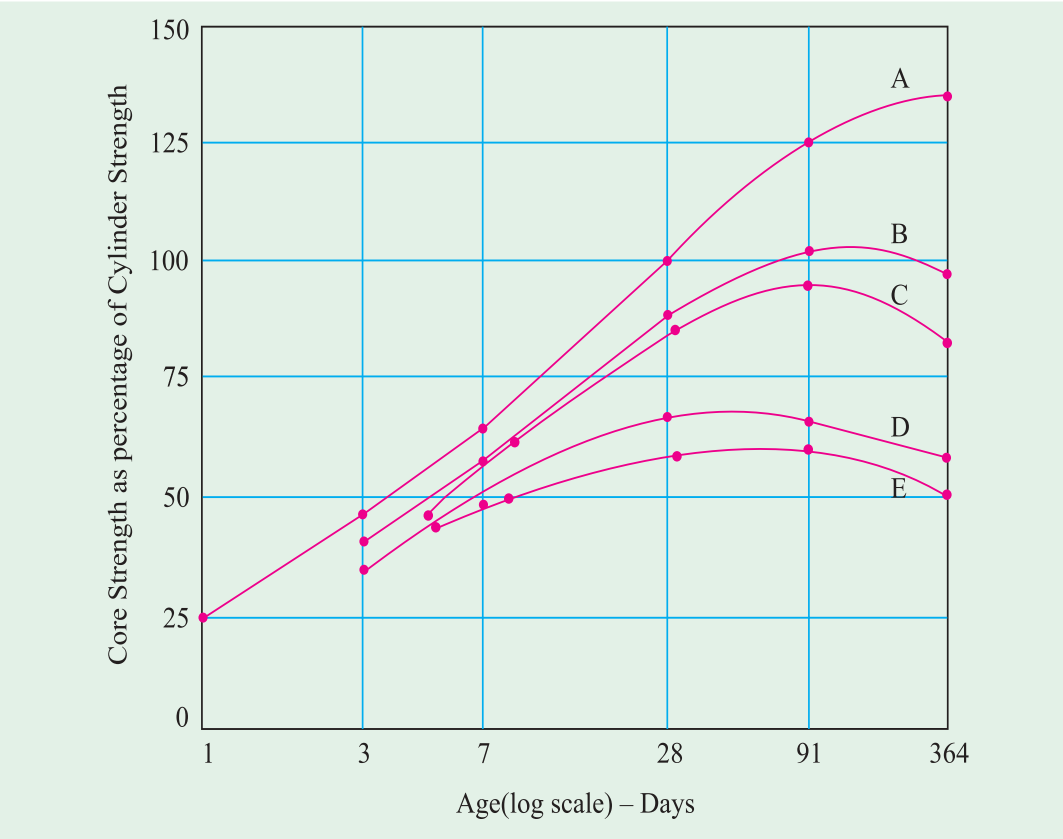
To have a standard condition for test specimens, it is usual to test a specimen immediately on removal from the curing water tank. This condition has the advantage of being better reproducible than a dry condition which includes greatly varying degrees of dryness.

It was earlier pointed out that contrary to expectations, the wet concrete exhibits higher modulus of elasticity. Strength and modulus of elasticity do not go hand in hand in the case of wet concrete.

Test Cores

The test specimen, cube or cylinder is made from the representative sample of concrete used for a particular member, the strength of which we are interested. As the member can not be in fact tested, we test the parallel concrete by making cubes or cylinders. It is to be understood that the strength of the cube specimen cannot be same as that of the member because of the differences with respect to the degree of compaction, curing standard, uniformity of concrete, evaporation, loss of mixing water etc. At best the result of cube or cylinder can give only a rough estimate of the real strength of the member.

To arrive at a better picture of the strength of the actual member, attempts are made to cut cores from the parent concrete and test the cores for strength. Perhaps this will give a better picture about the strength of actual concrete in the member.



Core can be drilled at the suspected part of the structure or to detect segregation or honey combing or to check the bond at construction joint or to verify the thickness of pavement.

The disadvantages are that while cutting the core, the structural integrity of the concrete across the full cross-section may be affected to some extent and secondly that the diameter to height ratio may be other than that of the standard cylinder. Capping of both ends will be required which will again introduce some differences in the strength. Existence of reinforcement will also present difficulty in cutting a clean core.

The cores cut to determine the strength of concrete of the actual structure may also indicate segregation and honey combing of concrete. In some cases, the beam specimens are also sawn from the road and airfield slabs for finding flexural strength. In practice, it is seen that the strength of the core is found to be less than that of the strength of standard cylinders. Apart from other reasons, it is mainly because site curing is invariably inferior to curing under standard moist condition.

Strength of Cores

The reduction in strength of cores appear to be greater in stronger concrete. The reduction in the strength can be as high as 15 per cent for 40 MPa concrete. Generally, a reduction of 5 to 7 per cent is considered reasonable. It has been reported by many investigators that in situ concrete gains very little strength after 28 days. Tests on high strength concrete show that, although the strength of cores increase with age, the core strength, even up to the age of 1 year, remains lower than the strength of standard 28 day cylinders. Fig. 10.8 and Table. 10. 2 illustrates the above statements.

Table 10.2. Development of strength of Cores with Age

Age days	Strength MPa		Core strength as a proportion of strength of
	Standard cylinders	Cores	28-day standard cylinder
7	66.0	57.9	0.72
28	80.4	58.5	0.73
56	86.0	61.2	0.76
180	97.9	70.6	0.88
365	101.3	75.4	0.94

Non-Destructive Testing Methods

Non-destructive methods have been in use for about four decades. In this period, the development has taken place to such an extent that it is now considered as a powerful method for evaluating existing concrete structures with regard to their strength and durability apart form assessment and control of quality of hardened concrete. In certain cases, the investigation of crack depth, microcracks, and progressive deterioration are also studied by this method.

Though non-destructive testing methods are relatively simple to perform, the analysis and interpretation of test results are not so easy. Therefore, special knowledge is required to


A view of rotary core cutting drill with necessary arrangement, ready to extract 50 mm dia core.

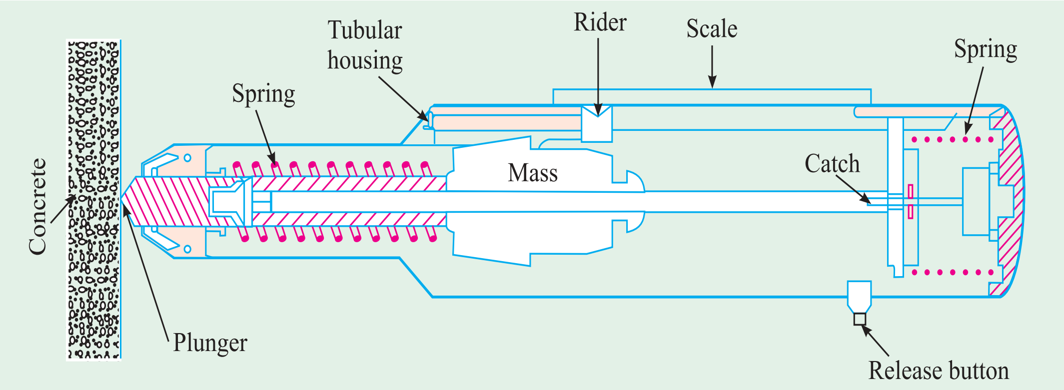
analyses the hardened properties of concrete. In the non-destructive methods of testing, the specimen are not loaded to failure and as such the strength inferred or estimated cannot be expected to yield absolute values of strength. These methods, therefore, attempt to measure some other properties of concrete from which an estimate of its strength, durability and elastic parameters are obtained. Some such properties of concrete are hardness, resistance to penetration of projectiles, rebound number, resonant frequency and ability to allow ultrasonic pulse velocity to propagate through it. The electrical properties of concrete, its ability to absorb, scatter and transmit X-rays and Gamma-rays, its response to nuclear activation and its acoustic emission allow us to estimate its moisture content, density, thickness and its cement content. Based upon the above, various non-destructive methods of testing concrete have been developed:

1. *Surface hardness tests: These are of indentation type, include the Williams testing pistol and impact hammers, and are used only for estimation of concrete strength.*
2. *Rebound test: The rebound hammer test measures the elastic rebound of concrete and is primarily used for estimation of concrete strength and for comparative investigations.*
3. *Penetration and Pull out techniques: These include the use of the Simbi hammer, Spit pins, the Windsor probe, and the pullout test. These measure the penetration and pullout resistance of concrete and are used for strength estimations, but they can also be used for comparative studies.*
4. *Dynamic or vibration tests: These include resonant frequency and mechanical sonic and ultrasonic pulse velocity methods. These are used to evaluate durability and uniformity of concrete and to estimate its strength and elastic properties.*
5. *Combined methods: The combined methods involving ultrasonic pulse velocity and rebound hammer have been used to estimate strength of concrete.*
6. *Radioactive and nuclear methods: These include the X-ray and Gamma-ray penetration tests for measurement of density and thickness of concrete. Also, the neutron scattering and neutron activation methods are used for moisture and cement content determination.*
7. *Magnetic and electrical methods: The magnetic methods are primarily concerned with determining cover of reinforcement in concrete, whereas the electrical methods, including microwave absorption techniques, have been used to measure moisture content and thickness of concrete.*

8. *Acoustic emission techniques: These have been used to study the initiation and growth of cracks in concrete.*
9. *Surfaces Hardness Methods: The fact that concrete hardens with increase in age, the measure of hardness of surface may indicate the strength of concrete. Various methods and equipments are devised to measure hardness of concrete surface. William testing pistol, Frank spring hammer, and Einbeck pendulum hammer are some of the devices for measuring surface hardness.*

Schmidt's Rebound Hammer

Schmidt's rebound hammer developed in 1948 is one of the commonly adopted equipments for measuring the surface hardness. The sectional view of the hammer is shown in Figure 10.9.



It consist of a spring control hammer that slides on a plunger within a tubular housing. When the plunger is pressed against the surface of the concrete, the mass rebound from the plunger. It retracts against the force of the spring. The hammer impacts against the concrete and the spring control mass rebounds, taking the rider with it along the guide scale. By pushing a button, the rider can be held in position to allow the reading to be taken. The distance travelled by the mass, is called the rebound number. It is indicated by the rider moving along a graduated scale.

Each hammer varies considerably in performance and needs calibration for use on concrete made with the aggregates from specific source. The test can be conducted horizontally, vertically—upwards or onwards or at any intermediate angle. At each angle the rebound number will be different for the same concrete and will require separate calibration or correction chart. Fig.10.11 shows the typical relationship between compressive strength and rebound number with hammer horizontal and vertical on a dry or wet surface of concrete.

Limitation: *Although, rebound hammer provides a quick inexpensive means of checking uniformity of concrete, it has serious limitations and these must be recognised. The results are affected by:*

(a) *Smoothness of surface under test.*
(b) *Size, shape and rigidity of the specimen.*
(c) *Age of specimen.*
(d) *Surface and internal moisture condition of the concrete.*
(e) *Type of coarse aggregate.*

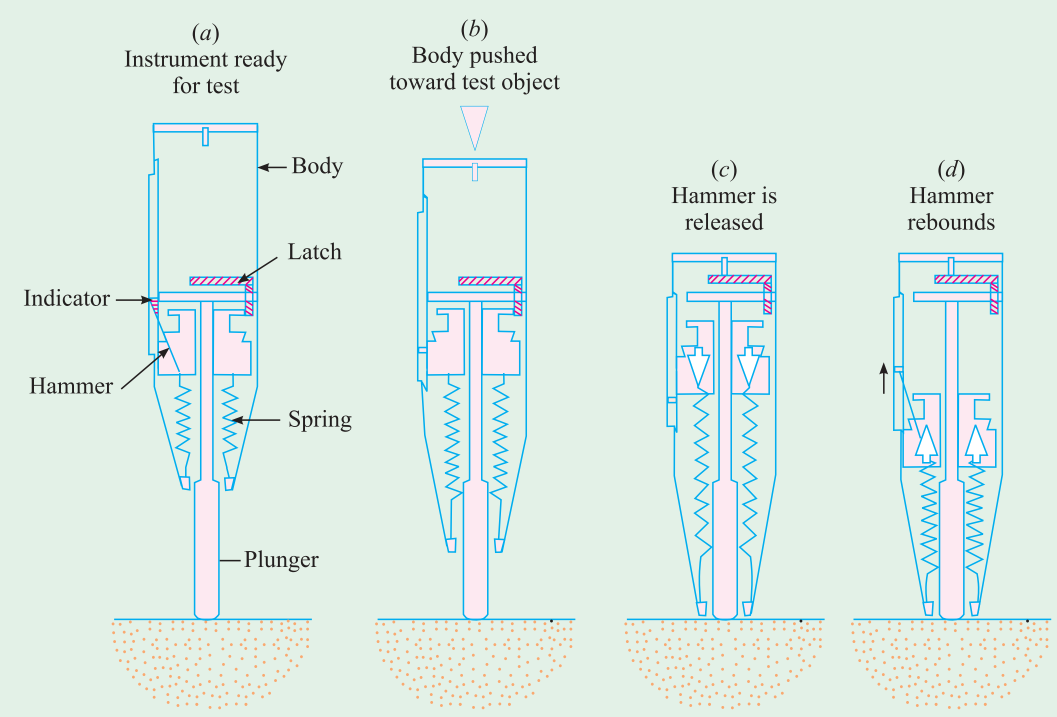


Fig. 10.10. Schematic cross section of rebound hammer showing operating principle

Concrete test hammer, normal

Concrete test hammer, digital

Testing anvil

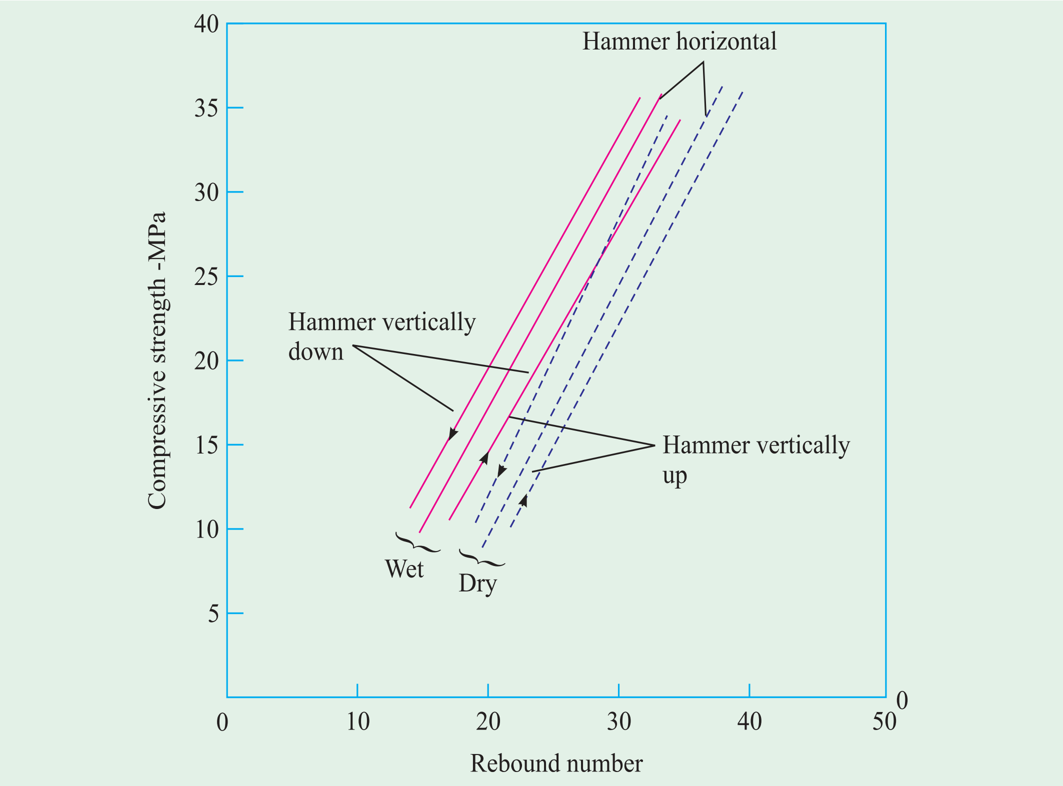
(f) Type of cement.

(g) Type of mould.

(h) Carbonation of concrete surface.

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



A view of Rebound Hammer connected with digital recording monitor and Test Anvil for calibration.

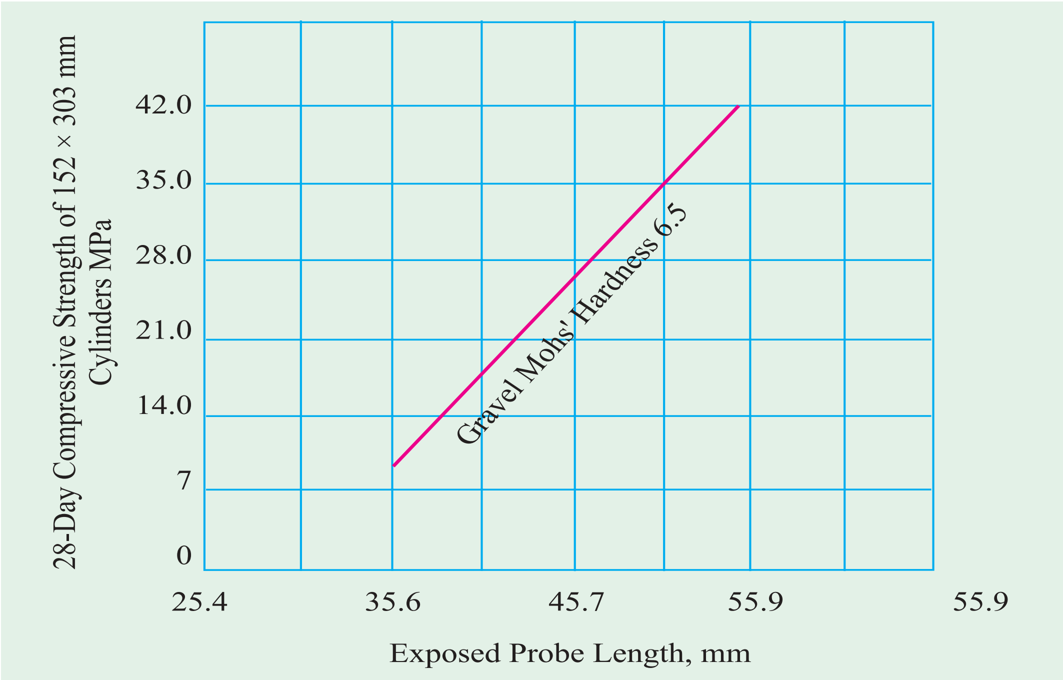
among various research workers regarding the accuracy of estimation of strength from rebound readings. The variation of strength of a properly calibrated hammer may lie between ±15% and ±20%.

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. Fig. 10.11 shows the relationship between compressive strength of concrete cylinders and rebound numbers.[10.6]

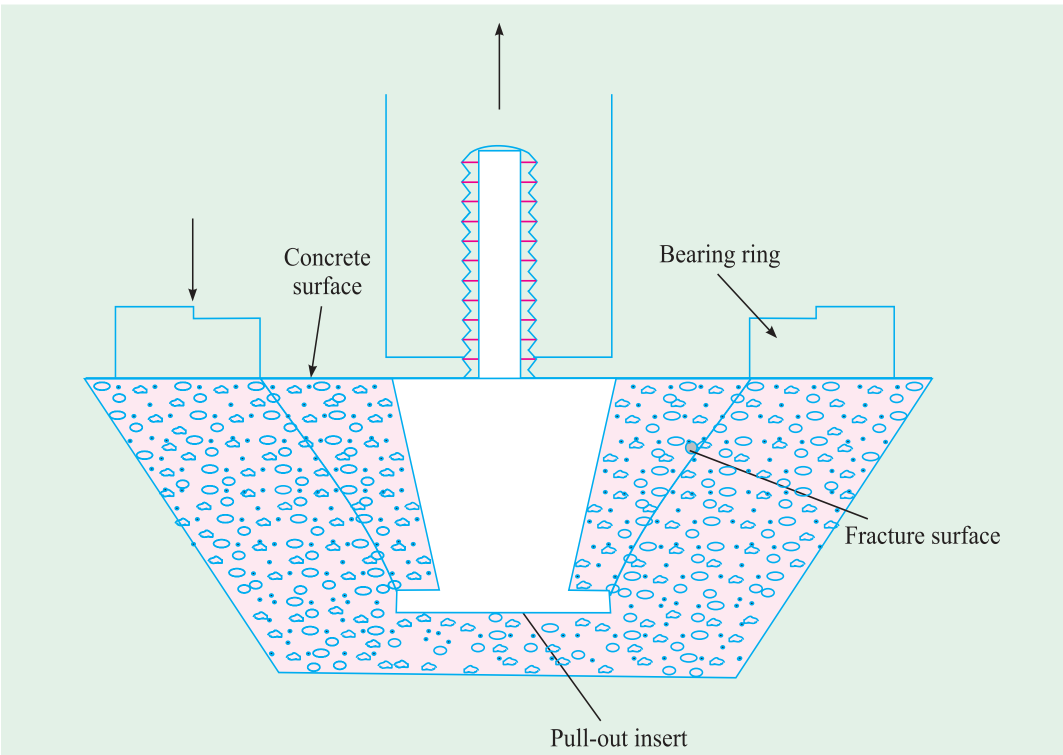
During 1965 and 1967 an international survey on the use of the Schmidt rebound hammer was carried out by RILEM. Majority of those who spoke were against the use of Schmidt rebound hammer in acceptance testing. The consensus was that, "the Schmidt rebound hammer is useful to very useful in checking uniformity of concrete and comparing one concrete against another but it can only be used as a rough indication of concrete strength in absolute terms".

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



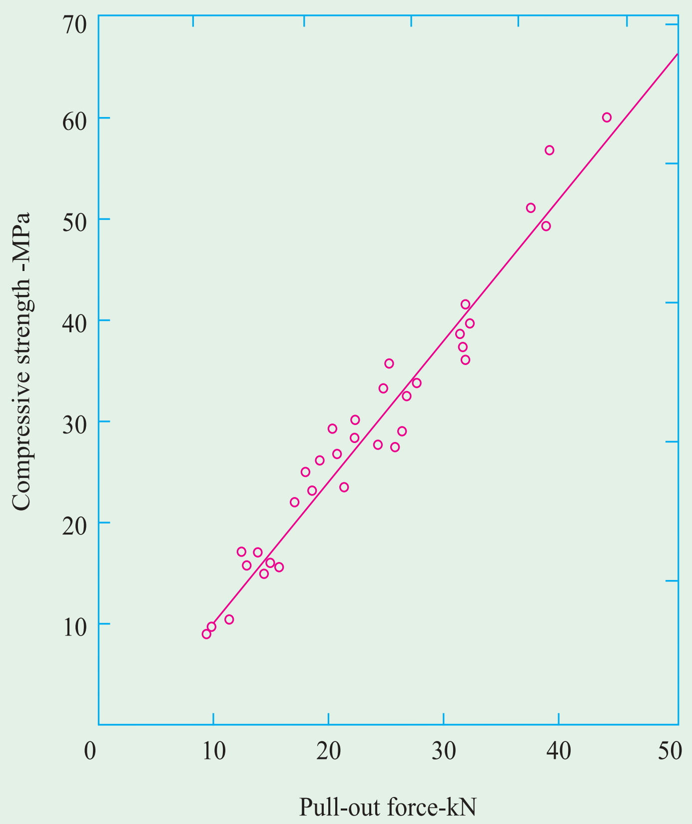
concrete and the depth of borehole was correlated to compressive strength of concrete cubes. In the other technique, the probing of concrete was achieved by blasting with spit pins and the depth of penetration of the pins was correlated with compressive strength of concrete.



The accuracy of this test was found to be ±25%. However, it is further seen that, "Simbi" and spit pins were more effected by the arrangement of coarse aggregate, than the tests using rebound hammers.

During 1964 and 1966, a technique known as the "Windsor Probe" was advanced for testing concrete in the laboratory and in situ. The windsor probe is a hardness tester of the surface of the concrete. It is an equipment consisting of a powder activated gun, hardened alloy probes, loaded cartridges, and depth gauge for measuring penetration of probes. The probe is driven into the concrete by firing of a precision powder charge cartridges. The exposed length is measured by calibrated depth gauge and this is correlated to the strength of concrete cylinders. Fig. 10.12 shows the relationship between exposed probe length and 28 day-compressive strength.[10.7]

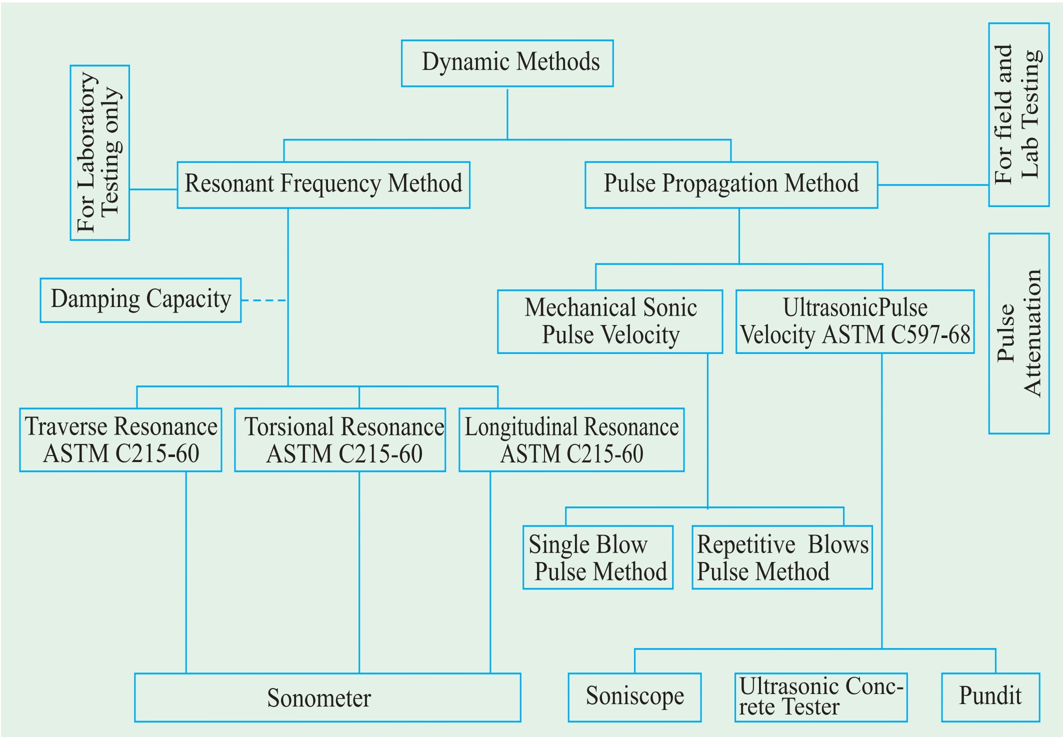
The windsor probe test cannot be really considered as a non-destructive testing, as it makes a hole and damages the structure. It can only be considered non-destructive to the extent that concrete can be tested in situ and structural members. In case of big structures like pavements or retaining walls etc., the structure need not be discarded.



The Windsor probe test is basically a hardness tester and, like other hardness testers, should not be expected to yield accurate absolute values of strength of concrete in a structure. However, like the "Schmidt rebound hammer", the probe test provides a good method for determining the relative strength of concrete in the same structure or relative strength in different structures without extensive calibration with specific 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. Figure 10.14 shows the relationship between compressive strength and pullout strength. [10.8]



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.

The velocity of sound in a solid can be measured by determining the resonant frequency of specimen or by recording the time of travel of short pulses of vibration passing through the samples. In non-destructive testing of concrete, either resonance method or pulse velocity techniques could be adopted. Figure 10.15 shows dynamic methods of testing concrete.

Ultrasonic Pulse Velocity Test Equipment

Resonant Frequency Method

This method is based upon the determination of the fundamental resonant frequency of vibration of a specimen.

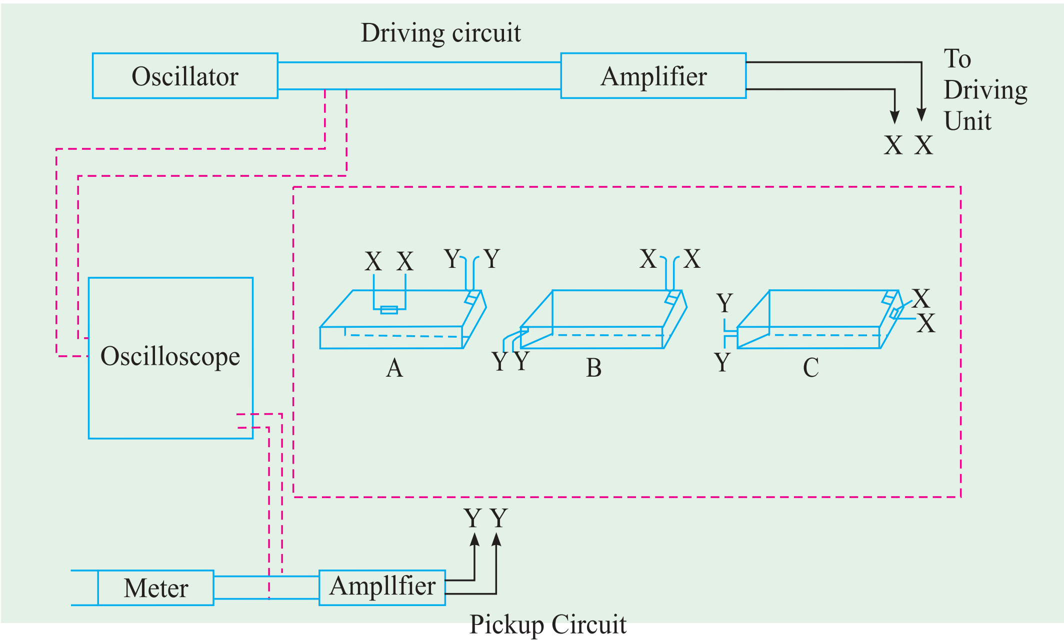
The resonance is indicated by the point of maximum amplitude for the various driving frequencies generated. The equipment used for this is usually known as 'Sonometer". Resonant frequency methods are mostly used in the laboratory. Figure 10.16 shows schematic diagram of a typical apparatus.

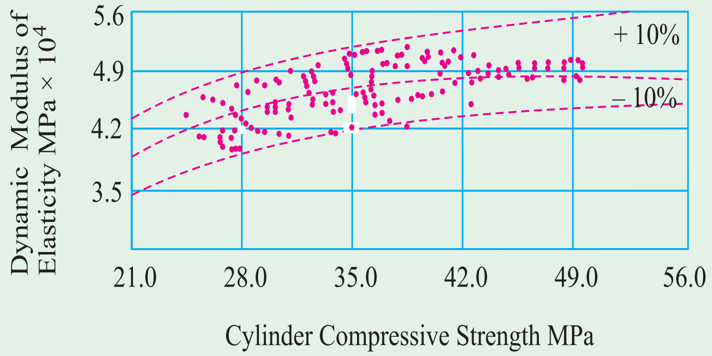
Usefulness of Resonant Frequency Method

These tests can normally be carried out only on small sized specimens in a laboratory rather than on structural members in the field. The possibility of vibrating structural members at resonance is neither practical nor desirable. The size of specimens in these tests is usually limited to 150 x 300 mm cylinders or 75 x 75 x 300 mm prisms.

The equations for the calculation of dynamic modulus involve "shape factor" corrections. This necessarily limits the shape of the specimens to cylindrical or prismatical types. Any deviation from the standard shapes can render the application of shape factor corrections rather complex.

Notwithstanding the above limitations, the resonance tests do provide an excellent means for studying the deterioration of concrete specimens subjected to repeated cycles of freezing and thawing and to deterioration due to acidic and alkali attack. The use of resonance tests in the determination of damage by fire has also been reported.





The resonant frequency test results are often used to calculate dynamic Young's modulus of elasticity of concrete but the values obtained are somewhat higher than those obtained with standard static tests carried out at lower rates of loading. The use of dynamic Young's modulus in design calculations is not recommended.

Various investigators have published correlations between the strength of concrete and its dynamic modulus of elasticity. (Figure 10.17). The indiscriminate use of such correlations to predict compressive and/or flexural strength of concrete is strongly discouraged unless similar relationships have been established in the laboratory for the particular concrete under investigation.

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.

The pulses can be generated either by hammer blows or by the use of an electroacoustic transducer. Electroacoustic transducers are preferred as they provide better control on the type and frequency of pulses generated. The instrument used is called "Soniscope".

Ultrasonic pulse velocity method consists of measuring the time of travel of an ultrasonic pulse, passing through the concrete to be tested. The pulse generator circuit consists of electronic circuit for generating pulses and a transducer for transforming these electronic pulses into mechanical energy having vibration frequencies in the range of 15 to 50 kHz. The time of travel between initial onset and the reception of the pulse is measured electronically. The path length between transducer divided by the time of travel gives the average velocity of wave propagation.

Recently, battery operated fully portable digitised units have become available in U.K. One such unit is called "PUNDIT" (Protable Ultrasonic Non-destructive Digital-Indicating Tester.). It only weights 3 kgs.[10.10]

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.*

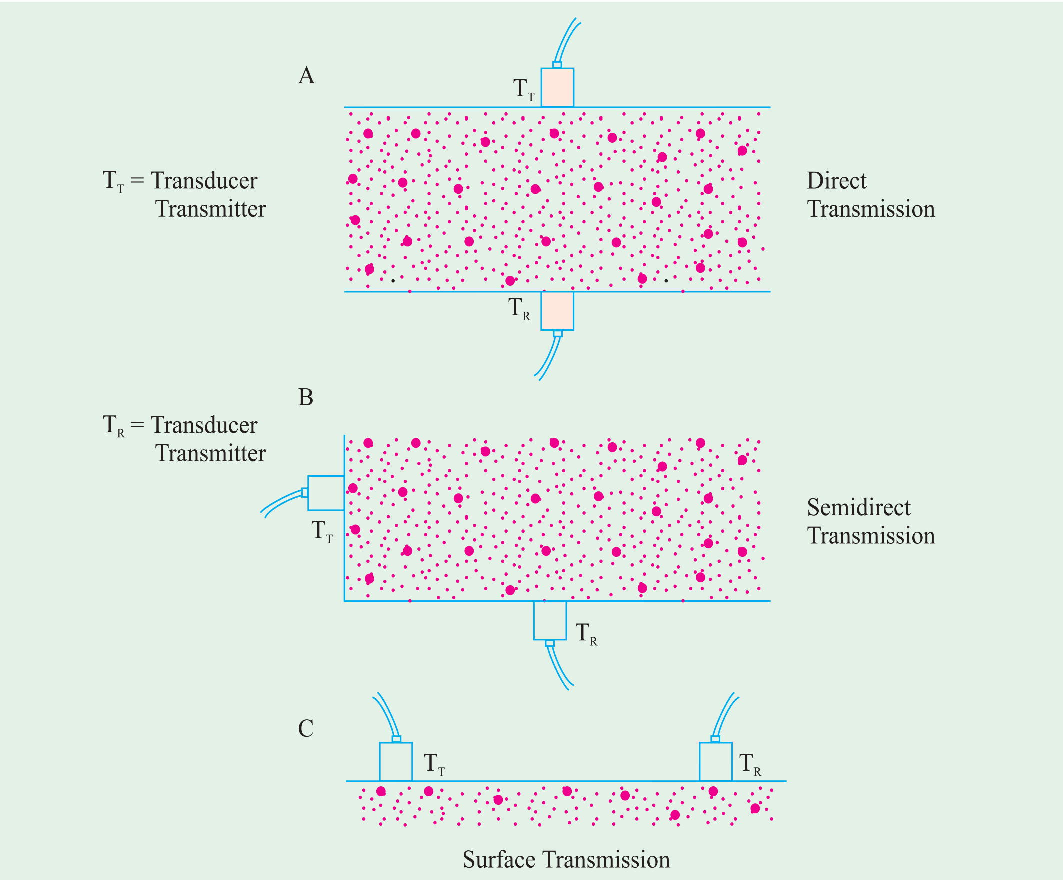
(c) *Surface transmission.*

Figure 10.18 shows the methods of measuring.

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 microcracking 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. The detailed corrections to pulse velocity measurements due to change in temperature are given in Table 10.3.*

Table 10.3. Corrections to Pulse Velocity Measurements due to changes in Temperature

Temperature °C	Correction per cent	
	Air-dried concrete	Water-saturated concrete
+60	+5.0	+4.0
+50	+3.5	+2.8
+40	+2.0	+1.7
+20	0.0	0.0
0	– 0.5	– 1.0
– 4 & below	– 1.5	– 7.5

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.*

Generally, it is desirable to choose pulse paths that avoid the influence of reinforcing steel. However, when it is not possible to do so, the measured values have to be corrected by taking into account the proximity of the pulse path to the reinforcing steel, the quantity and orientation of the steel with respect to the propagation path, and the pulse velocity in the concrete.

When the axis of reinforcing bars is perpendicular to the direction of propagation and the quantity of reinforcement is small, the influence of the reinforcement on the pulse velocity is generally small. The correction factors are of the order of 1– 4% depending upon the quality of the surrounding concrete the higher the quality of concrete, the smaller the correcting factor.

When the axis of the reinforcing bars is parallel to the direction of propagation of the pulse, the influence of reinforcement cannot be avoided easily. The pulse velocity measurements can be corrected but correction factors are of approximate nature only, and in case of two-way reinforcement it is almost impossible to make any reliable corrections.

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 soniscope 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 soniscope 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. Table 10.4 gives the pulse velocity ratings, as given by Leslie and Cheesman.*

Table 10.4. Suggested Pulse Velocity for Concrete[10.11]

Pulse velocity (m/s)					*General conditions*
4575	...	...	...	...	Excellent
3660—4575	...	...	...	...	Good
3050—3660	...	...	...	...	Questionable
2135—3050	...	...	...	...	Poor
2135	...	...	...	...	Very poor

Table 10.5. Velocity Criterion for Concrete Quality Grading (As per IS : 13311-Part I)

SL. No.	*Pulse velocity by cross-probing, km/sec.*	*Concrete quality greading*
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

Table 10.6. Velocity Criterion for Concrete Quality Grading by Surface Probing (As per NCBM)

SL. No.	Pulse velocity by surface probing, km/sec.	Concrete quality grading
1.	Above 3.5	Excellent
2.	3.0 to 3.5	Good
3.	2.5 to 3.0	Medium
4.	Below 2.5	Poor

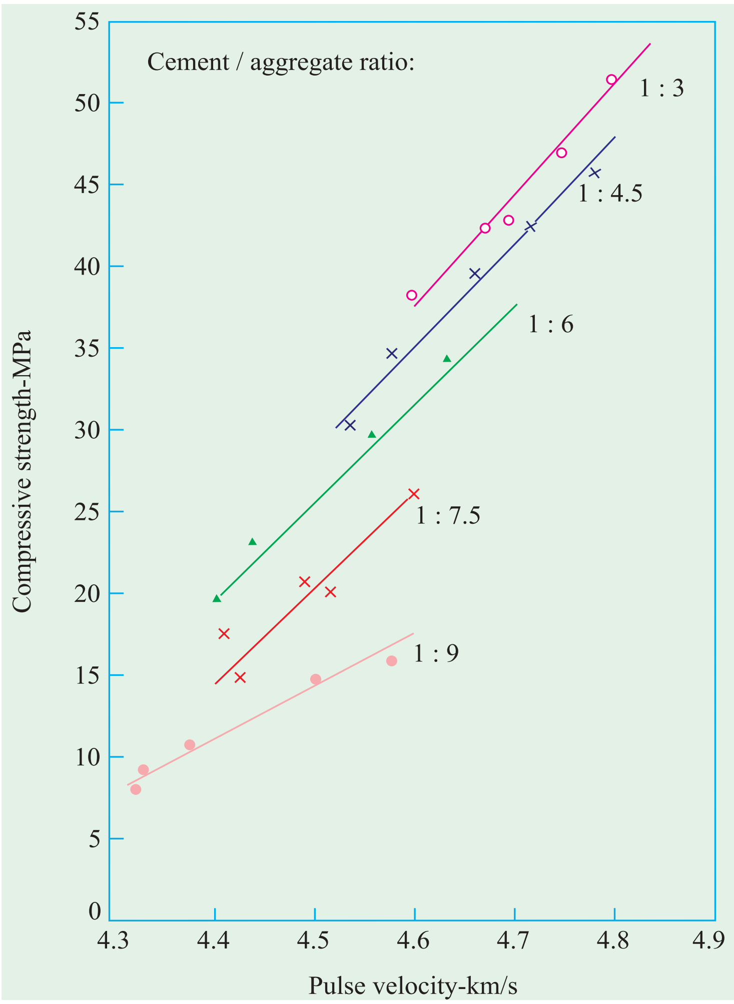
Determination of pulse modulus of elasticity: *Theoretically, the values of the pulse modulus of elasticity calculated from the readings obtained with the soniscope or the ultrasonic concrete tester should be the same as those obtained with resonant frequency techniques. However, this has not been found 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 therefrom. If it is desired to compute modulus of elasticity from the pulse velocity, the formulae given under Chapter 8 should be used.

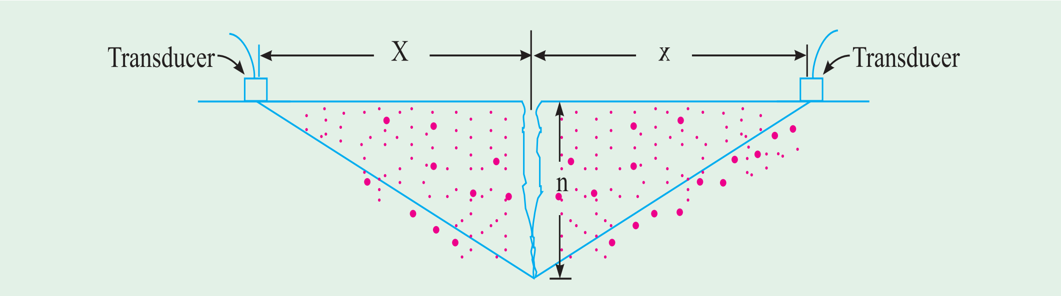
Estimation of strength of concrete: *Various researchers have attempted to correlate compressive and flexural strength of concrete with pulse velocity. Fig 10.19 show relationship between pulse velocity and compressive strength for various aggregate/cement ratio.* [10.12]

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

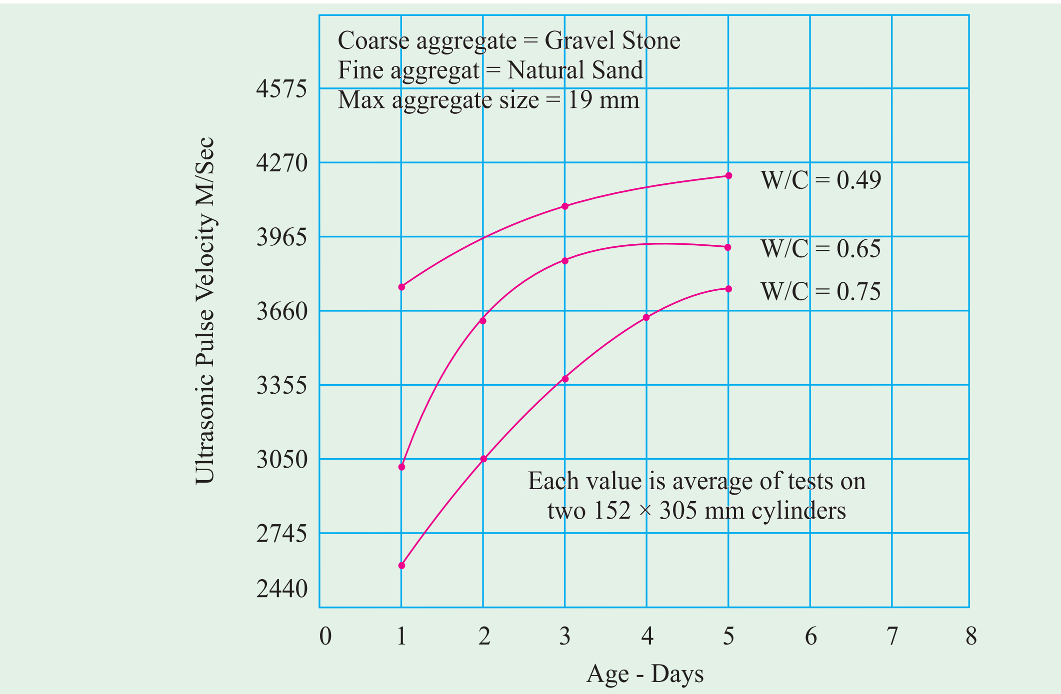
Studies on durability of concrete: *Durability of concrete under freeze-thaw action and the aggressive environments such as sulphate attack and acidic waters, have been studied by various investigators using the pulse velocity technique to assess damage.*

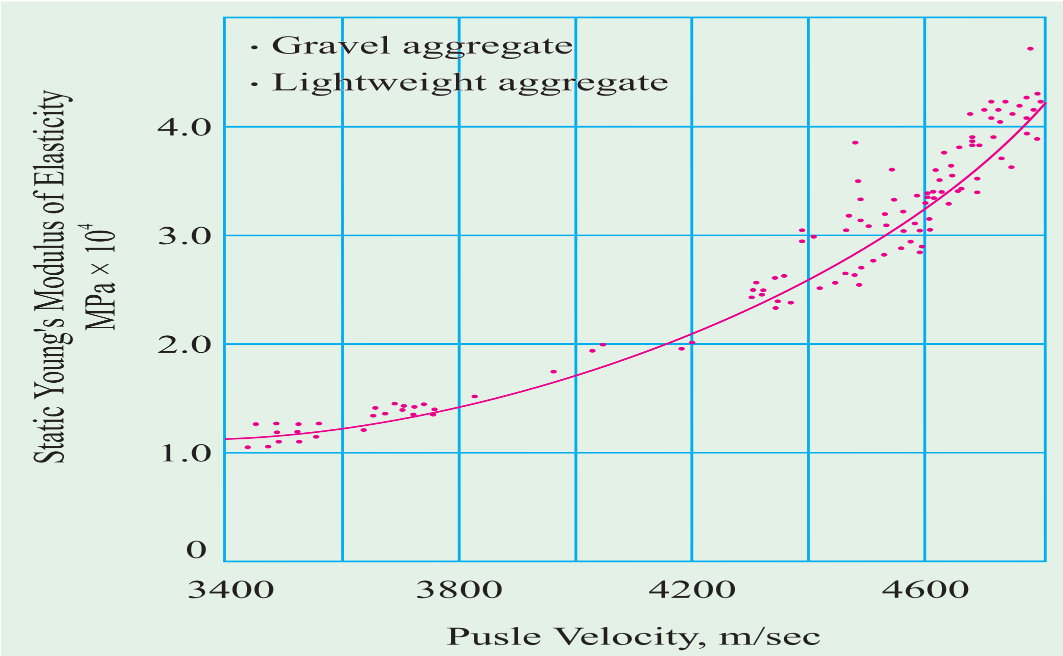


Pulse velocity techniques *have been successfully used for the measurement and detection of cracks. The basic principle of crack detection is that, if the crack is of appreciable width and considerable depth, perpendicular to the test path, no signal will be received at the receiving transducer. If the 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. Figure 10.20 shows the principle involved in measurements of crack depth.*



Measurement of deterioration of concrete due to fire exposure: *Pulse velocity techniques have been used to estimate the deterioration due to fire. In one of the experiments, prisms of the size 88 x 102 x 406 mm have been exposed to fire for 1 hour at temperatures ranging from 100° to 1000°C. After the exposure, the specimens were removed from the furnace and allowed to cool to room temperature. Pulse velocity was then measured using the ultrasonic concrete tester, following this, the prisms were tested in flexure. The per cent loss in pulse*





velocity followed very closely the per cent loss in flexural strength of test prisms after fire exposure.

Determination of the time of removal of form work can be sometimes assessed by measuring the pulse velocity. Figure 10.21 shows the relationship between age and pulse velocity for different water/cement ratio.

Pulse velocity techniques have also been used for the measurement of thickness of concrete pavements.

Relationship between Pulse Velocity and Static Young's Modulus of Elasticity

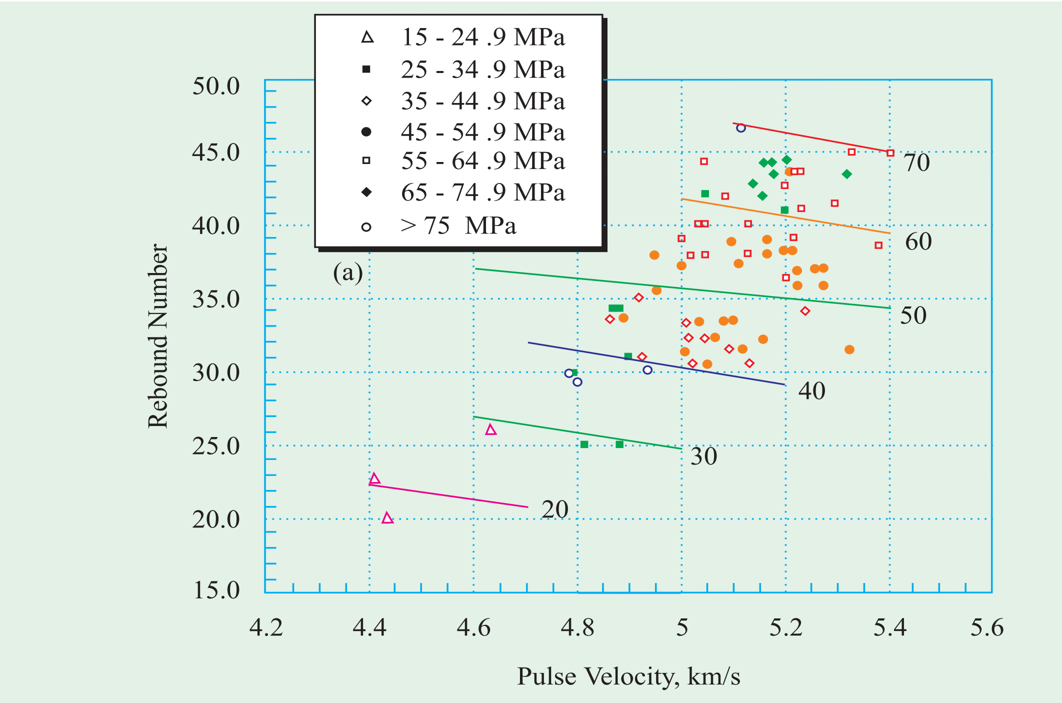
An empirical relationship between pulse velocity and Static Young's Modulus of elasticity is shown in Figure 10.22. Using this relationship, it may be possible to estimate the value of Young's modulus elasticity at those points in a structure, where pulse velocity measurements are taken. It may be remembered that pulse modulus which is called "Dynamic Modulus" has been discussed earlier. Dynamic modulus is invariably higher than static modulus.

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. Fig.10.23 shows the relationship between Pulse Velocity and Rebound number for various strength of concrete.

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 penerate 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.

A view of Profometer with attached Scanner to locate the reinforcements and to determine spacing, diameter and concrete cover.

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.

A view of Resistivity meter well connected with Wenner four probe, ready to measure the resistivity of concrete.

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. A concrete pavement has a resistivity characteristic that is different from that of the underlying subgrade layers. A change in the slope of the resistivity verses depth curve is used to estimate the depth of concrete pavement.

Tests on Composition of Hardened Concrete

Sometimes the dispute regarding the quality of work may arise between contractor and department and this dispute may be submitted to arbitration. In such cases, it will be necessary that the composition of the hardened cement concrete may be required to be ascertained by chemical analysis.

Determination of Cement Content

The method of finding out the cement content is based on the fact that the silicates in Portland cement are much more readily decomposed and made soluble in dilute hydrochloric acid than the solubility of silica contained in the aggregates. Similarly, the lime contained in cement is much more soluble than lime content in aggregates, with the exception of lime stone aggregates.

A view of Corrosion Analyser for half-cell potential measurement with the help of copper/copper sulphate reference electrode.

The procedure is to crush a representative sample of the concrete *and dehydrate it at a temperature of 550°C for 3 hours. A small portion of the sample is taken and treated with 1:3 hydrochloric acid. The quantity of silica is determined by standard chemical methods.*

The filtrate from the silica determination contains soluble calcium oxide from the aggregate and the cement, and further calculations depend on whether or not the aggregate is largely siliceous. If the original aggregate is available its solubility should be tested.

From the contents of soluble silica and calcium oxide the cement content in the original volume of the sample can be calculated, using A.S.T.M. Standard method C 85-66. These results are reliable and can be used to check the cement content of different parts of a structure, e.g., when it is desired to establish whether or not segregation has taken place. The accuracy of the test is, however, lowest for mixes with low cement contents, and, it is often in this type of mix that the exact value of cement content is required. Furthermore, the test depends on the knowledge of the chemical composition of aggregate, which may not be available for testing. When large amounts of both soluble silica and calcium oxide are liberated from the aggregate, the method is not reliable.

More complex techniques are prescribed by B.S. 1881 : Part 6 : 1971 but it should be noted that chemical tests are rather, expensive and are used only in resolving disputes, and not as a means of control of the quality of concrete.

Determination of the Original Water/Cement Ratio

A method of estimating the water/cement ratio that existed at the time of placing of a concrete mix, now hardened, has been developed by Brown. In essence, this involves determining the volume of the capillary pores and the weight of cement and combined water.

A sample of concrete is oven-dried at 105°C and the air is removed from the pores under vacuum. The pores are then refilled with carbon tetrachloride, whose weight is measured, and hence the weight of the water which originally occupied the pores can be calculated. Since the voids formed through air entrainment are discontinuous they remain filled with air when the vacuum is applied and no water is absorbed in them. The result of the test is thus unaffected by entrained air.

The sample is now broken up, the carbon tetrachloride having been allowed to evaporate, and the aggregate is separated out and weighed. The loss on ignition and the CO_2 *content of the remaining fine material are determined, and from these two quantities the weight of combined water can be calculated.*

The sum of the combined water and the pore water gives the original mixing water. The quantity of anhydrous cement can also be determined either in conjunction with this test or by the method described earlier and hence the water/cement ratio of the mix can be calculated within about 0.02 of the true value. The technique has been developed into a standard method of B.S. 1881 : Part 6 : 1971.

Physical Method

Polivka 10.15 has successfully used a "Point-count" method on a sawn and varnished surface of a dried concrete specimen to determine its cement content, total aggregate content, and fine/coarse aggregate ratio. The basis of the method is the fact that the relative volumes of the constituents of a heterogeneous solid are directly proportional to their relative areas in a plane section, and also to the intercepts of these areas along a random line. Furthermore, the frequency with which a constituent occurs at a given number of equally *spaced points along a random line is a direct measure of the relative volume of that constituent in the solid. Thus point-count by means of a stereo-microscope can rapidly give the volumetric proportions of a hardened concrete specimen.*

The aggregate and the voids (containing air or evaporable water) can be identified, the remainder being assumed to be hydrated cement. In order to convert the quantity of the latter to the volume of unhydrated cement, we have to know the specific gravity of dry cement and the non-evaporable water content of hydrated cement.

The test determines the cement content of the concrete within 10 per cent but the original water content or voids ratio cannot be estimated since no distinction is made in the test between air and water voids.

Accelerated Curing Test

Concrete is usually tested at the age of 7 days and 28 days. Concrete mixes are designed usually for 28 days strength and sometimes for 7 days strength. One will come to know whether the concrete has attained specified strength or not, at the end of 28 days or 7 days. At the work site, normally, concrete is placed daily. In some situations, concrete is poured daily, over the previoulsy laid concrete, as in the case of columns, retaining walls etc. The progress of laying concrete cannot be held up for 28 days or even 7 days until the strength is ascertained. When the concrete strength is known, after 28 days and if it happens to be inferior concrete, not satisfying the required strength, the engineer will be put to an embarrassing situation. Sometimes, it may so happen, that the upper lift may satisfy the strength requirement but the lower one may fail to satisfy the strength requirement. Some of the suggestions given to overcome such situations are devaluation of work, dismantling of all the works, redesigning and reducing the load of the structure above the level of such weak concrete, grouting of concrete etc. It can be said that none of the above suggestions are satisfactory.

Perhaps, finding out the strength of concrete in 8 hours time and correlating it to 28 days strength is the best method to overcome such situations. If one comes to know, in about 8 hours time, the 28 days strength, if the concrete does not satisfy, steps could be taken without any legal complication by replacing the faulty concrete. The problem is only to find out the 28 days strength, reliably in about 8 hours.

Many research workers worked in this directions to depict 28 days strength within a short period. Out of all the procedures, accelerated curing test developed by Prof. King is considered to be more accurate and easy for adoption.

In this test, standard concrete cubes are made. These cube moulds are covered both on top and bottom by cover plates and sealed with the grease at the contact surface, to prevent escaping of moisture from concrete. Cubes are placed in an airtight oven within 30 minutes of the addition of water and then switched on. The temperature is brought on to 93°C in about an hour. The cubes are kept at this temperature for a period of 5 hours. Then the cubes are stripped off and allowed to cool within half an hour. The total time spent is 7 hours. At the end of 7 hours the cube is crushed. Seven days or 28 days strength of the concrete is deduced from the standard curve established giving the relationship between King's accelerated curing test results and 7 and 28 days strength. The relationship is shown in Figure 7.4. [10.18]

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