Topic – 6 NON-DESTRUCTIVE TESTING

Non-Destructive Testing (NDT) is the examination of an object or material with technology that does not affect its future usefulness. NDT techniques do not harm or destroy the object under test. NDT can provide an excellent balance of quality control and cost-effectiveness without affecting manufacturing yield.

Non-destructive testing of concrete is a method to obtain the compressive strength and other properties of concrete from the existing structures. This test provides immediate results and actual strength and properties of concrete structure without destroy the object or structure.

These non-destructive methods may be categorized as penetration tests, rebound tests, pullout techniques, dynamic tests, radioactive tests, maturity concept pulse velocity meter, rebar & cover meter, half-cell potential meter, corrosion resistivity meter and core sampling. It is the purpose of this Digest to describe these methods briefly, outlining their advantages and disadvantages.

Importance of Non-destructive Tests are:

1. Estimating the in-situ compressive strength.

2. Estimating the uniformity and homogeneity.

3. Estimating the quality in relation to standard requirement.

4. Identifying areas of lower integrity in comparison to other parts.

5. Detection of presence of cracks, voids and other imperfections.

6. Monitoring changes in the structure of the concrete which may occur with time.

7. Identification of reinforcement profile and measurement of cover, bar diameter, etc.

8. Condition of pressurising/reinforcement steel with respect to corrosion.

9. Chloride, sulphate, alkali contents or degree of carbonation.

10. Measurement of Elastic Modulus.

11. Condition of grouting in pressurising cable ducts.

Methods of Non-Destructive Testing of Concrete Following are different methods of NDT on concrete:

1. Rebound hammer method

2. Ultrasonic pulse velocity method

3. Rebar & cover meter

4. Half-cell potential meter

5. Corrosion resistivity meter

6. Core sampling

Introduction Non-destructive testing of concrete is a method to obtain the compressive strength and other properties of concrete from the existing structures. This test provides immediate results and actual strength and properties of concrete structure. The standard method of evaluating the quality of concrete in buildings or structures is to test specimens cast simultaneously for compressive, flexural and tensile strengths. The main disadvantages are that results are not obtained immediately; that concrete in specimens may differ from that in the actual structure as a result of different curing and compaction conditions; and that strength properties of a concrete specimen depend on its size and shape. Although there can be no direct measurement of the strength properties of structural concrete for the simple reason that strength determination involves destructive stresses, several nondestructive methods of assessment have been developed. These depend on the fact that certain physical properties of concrete can be related to strength and can be measured by non-destructive methods. Such properties include hardness, resistance to penetration by projectiles, rebound capacity and ability to transmit ultrasonic pulses and X- and Y-rays. These non-destructive methods may be categorized as penetration tests, rebound tests, pullout techniques, dynamic tests, radioactive tests, maturity concept pulse velocity meter, rebar & cover meter, half-cell potential meter, corrosion resistivity meter and core sampling. It is the purpose of this Digest to describe these methods briefly, outlining their advantages and disadvantages.

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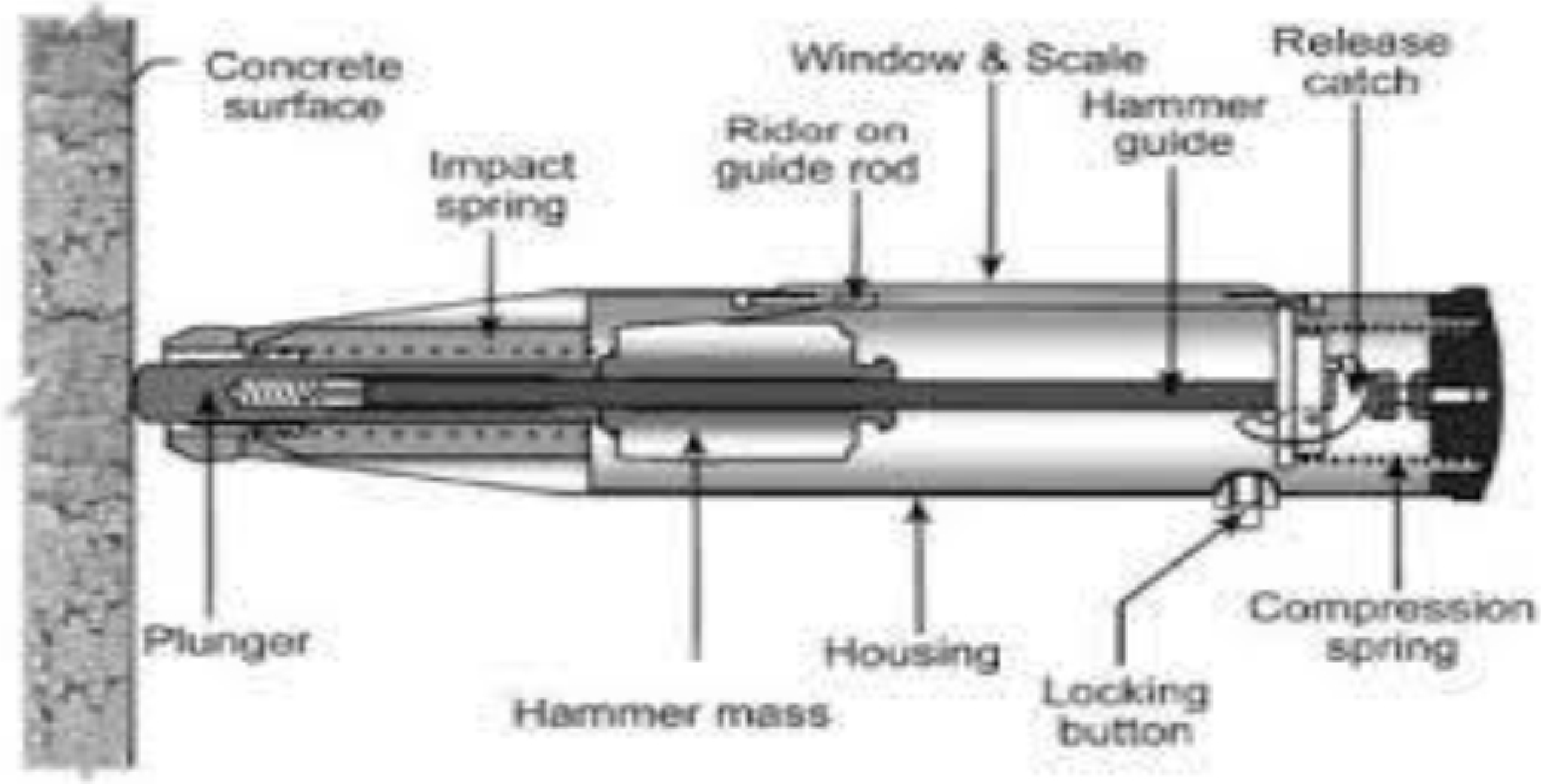
1. REBOUND HAMMER METHOD

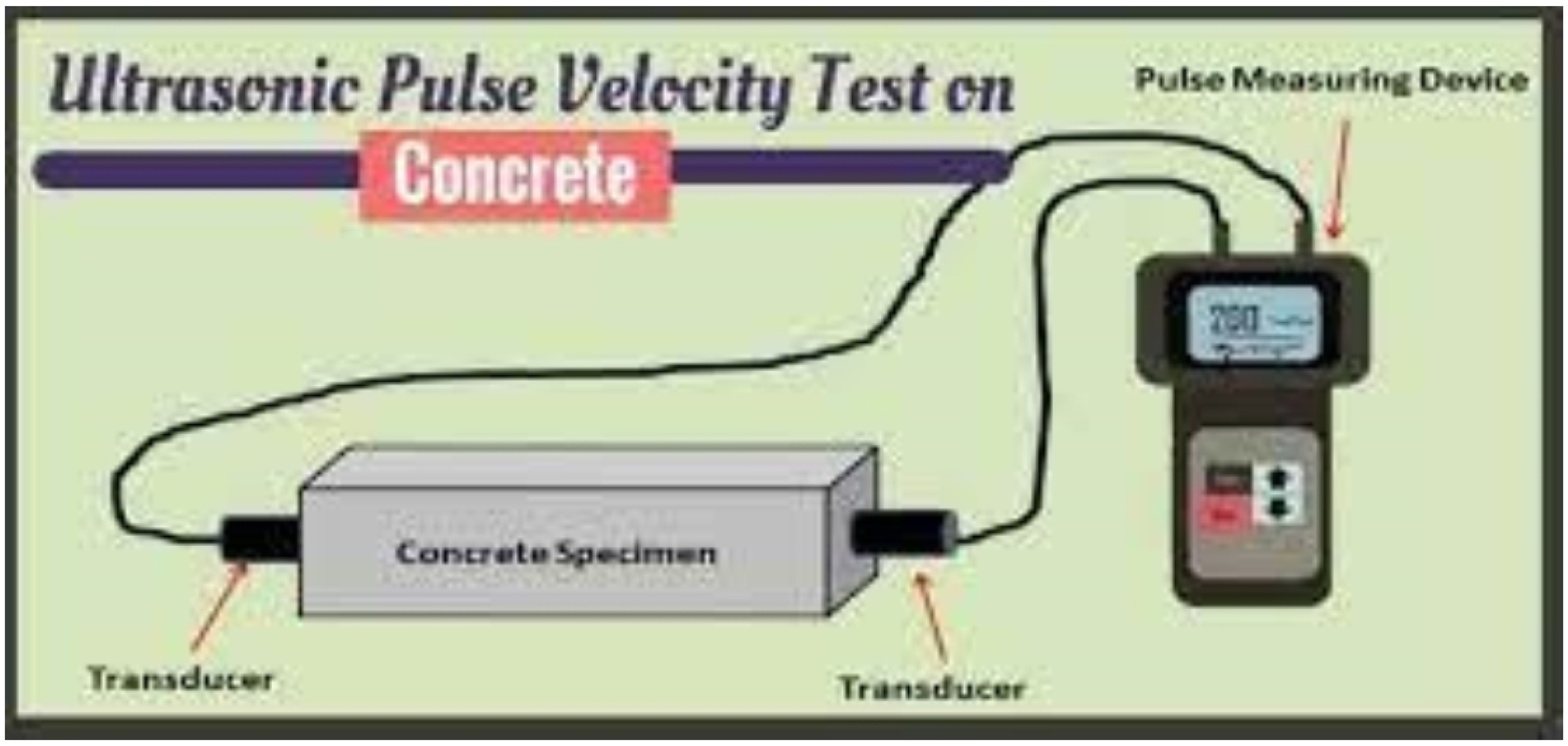
The rebound hammer is a surface hardness tester for which an empirical correlation has been established between strength and rebound number. The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer, which weighs about 4 lb (1.8 kg) and is suitable for both laboratory and field work. It consists of a spring-controlled hammer mass that slides on a plunger within a tubular housing. The hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale. The test surface can be horizontal, vertical or at any angle but the instrument must be calibrated in this position. Calibration can be done with cylinders (6 by 12 in., 15 by 30 cm) of the same cement and aggregate as will be used on the job. The cylinders are capped and firmly held in a compression machine. Several readings are taken, well distributed and reproducible, the average representing the rebound number for the cylinder. This procedure is repeated with several cylinders, after which compressive strengths are obtained.



Limitations and Advantages The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established. The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of surface.

2. ULTRASONIC PULSE VELOCITY METHODS

At present the ultrasonic pulse velocity method is the only one of this type that shows potential for testing concrete strength in situ. It measures the time of travel of an ultrasonic pulse passing through the concrete. The fundamental design features of all commercially available units are very similar, consisting of a pulse generator and a pulse receiver. Pulses are generated by shock-exciting piezo-electric crystals, with similar crystals used in the receiver. The time taken for the pulse to pass through the concrete is measured by electronic measuring circuits. Pulse velocity tests can be carried out on both laboratorysized specimens and completed concrete structures, but some factors affect measurement: There must be smooth contact with the surface under test; a coupling medium such as a thin film of oil is mandatory. It is desirable for path-lengths to be at least 12 in. (30 cm) in order to avoid any errors introduced by heterogeneity. It must be recognized that there is an increase in pulse velocity at below-freezing temperature owing to freezing of water; from 5 to 30°C (41 – 86°F) pulse velocities are not temperature dependent. The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity. It is therefore desirable and often mandatory to choose pulse paths that avoid the influence of reinforcing steel or to make corrections if steel is in the pulse path.



Applications and Limitations The pulse velocity method is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction. Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective or deteriorated concrete is present. High pulse velocity readings are generally indicative of good quality concrete. A general relation between concrete quality and pulse velocity is given in Table.

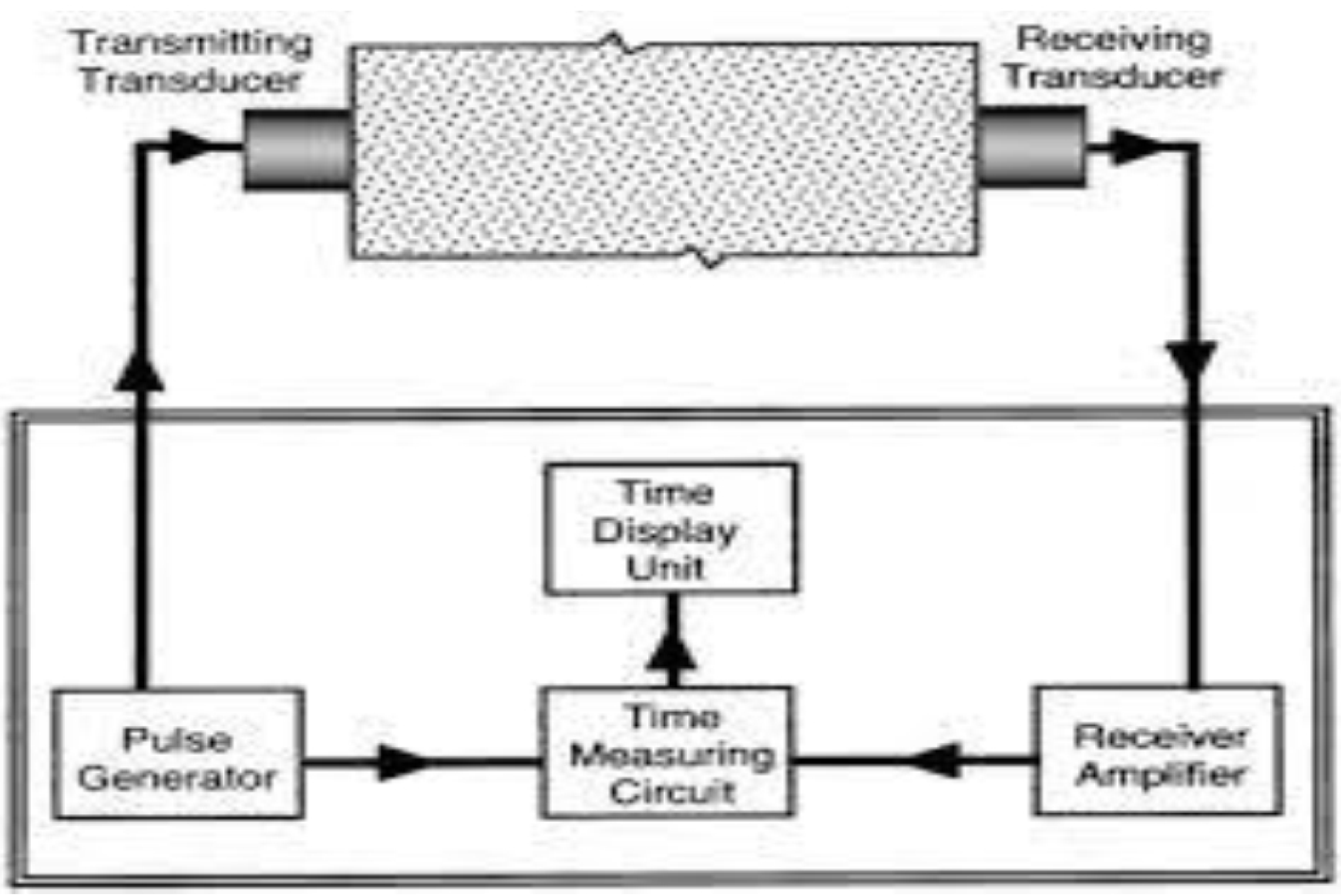


Table: Quality of Concrete and Pulse Velocity

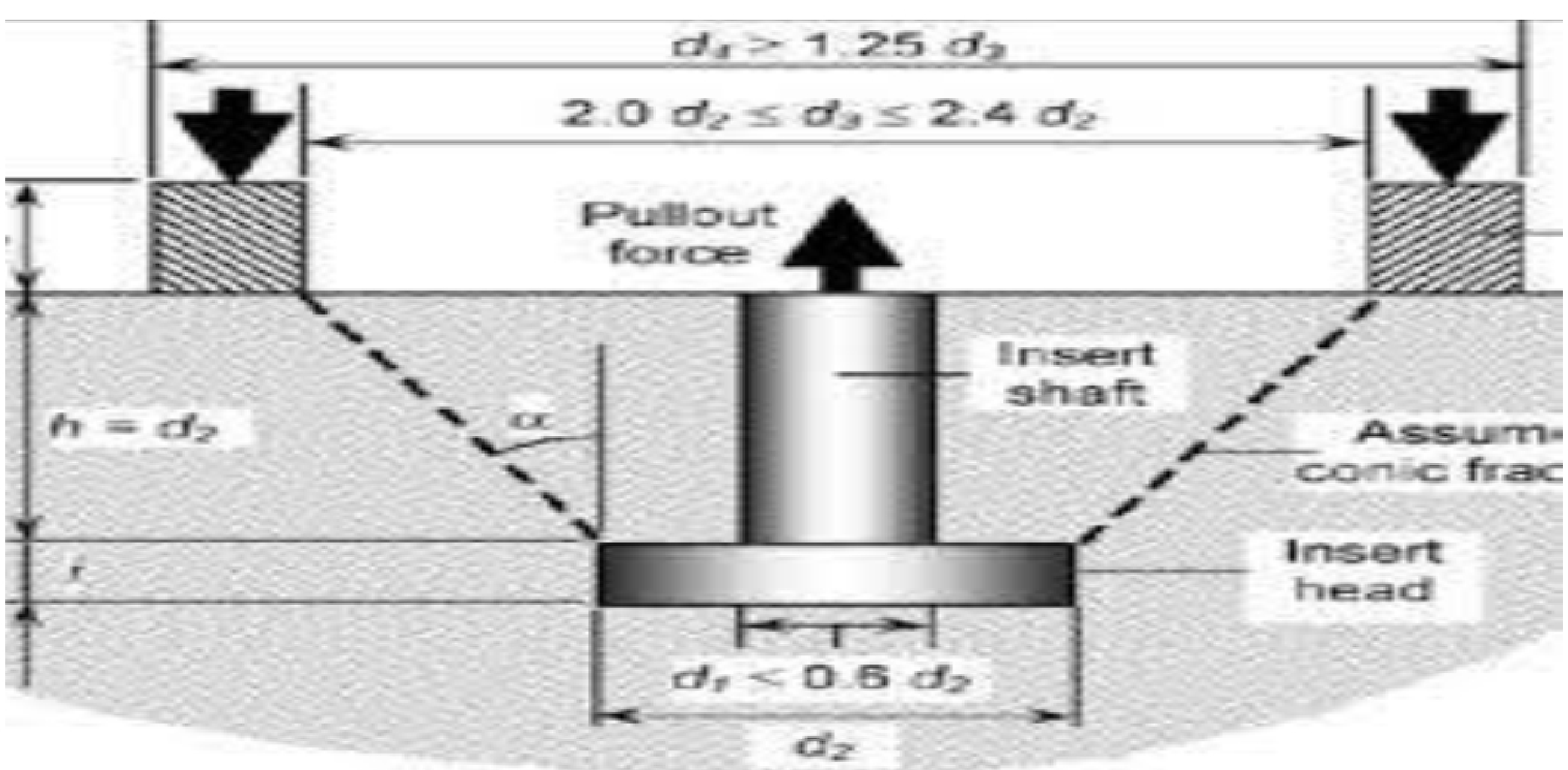
1	General Conditions	Pulse Velocity ft/sec
2	Excellent Above	15,000
3	Good	12,000-15,000
4	Questionable	10,000-12,000
5	Poor	7,000-10,000
6	Very Poor below	7,000

Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within ±20 per cent, provided the types of aggregate and mix proportions are constant.

The pulse velocity method has been used to study the effects on concrete of freeze-thaw action, sulphate attack, and acidic waters. Generally, the degree of damage is related to a reduction in pulse velocity. Cracks can also be detected. Great care should be exercised, however, in using pulse velocity measurements for these purposes since it is often difficult to interpret results. Sometimes the pulse does not travel through the damaged portion of the concrete. The pulse velocity method can also be used to estimate the rate of hardening and strength development of concrete in the early stages to determine when to remove formwork. Holes have to be cut in the formwork so that transducers can be in direct contact with the concrete surface. As concrete ages, the rate of increase of pulse velocity slows down much more rapidly than the rate of development of strength, so that beyond a strength of 2,000 to 3,000 psi (13.6 to 20.4 MPa) accuracy in determining strength is less than ±20%. Accuracy depends on careful calibration and use of the same concrete mix proportions and aggregate in the test samples used for calibration as in the structure. In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

4. PULL-OUT TESTS ON CONCRETE

A pull-out test measures, with a special ram, the force required to pull from the concrete a specially shaped steel rod whose enlarged end has been cast into the concrete to a depth of 3 in. (7.6 cm).The concrete is simultaneously in tension and in shear, but the force required to pull the concrete out can be related to its compressive strength. The pull-out technique can thus measure quantitatively the in-situ strength of concrete when proper correlations have been made. It has been found, over a wide range of strengths, that pull-out strengths have a coefficient of variation comparable to that of compressive strength.



Limitations and Advantages Although pull out tests do not measure the interior strength of mass concrete, they do give information on the maturity and development of strength of a representative part of it. Such tests have the advantage of measuring quantitatively the strength of concrete in place. Their main disadvantage is that they have to be planned in advance and pull-out assemblies set into the formwork before the concrete is placed. The pull-out, of course, creates some minor damage. The test can be non-destructive, however, if a minimum pull out force is applied that stops short of failure but makes certain that a minimum strength has been reached. This is information of distinct value in determining when forms can be removed safely.

5. REBAR & COVER METER

Cover meter test is a non-destructive test which is used to specify the location of reinforcement bars in concrete and determine the exact concrete cover needed. The magnetic rebar locator test plays a significant role in construction works because the information about the location of steel.

Rebar cover Meter

Bars, concrete cover, and bar sizes is essential, directly or indirectly, in many field applications. For instance, knowing the diameter of a bar and its location is needed to understand the spacing of bars and their placement in existing structures where drawing may not be available. Added to that, in cases where the core extracts of a concrete specimen are to be taken, the identification of the locations of rebars becomes essential to avoid the cutting of the same. It is important to note that the cover meter test is not applicable for certain types of bars such as Glass fiber and post tension or pretension strand.

Field Applications of Cover meter Test

1. Making drawings for old buildings for maintenance purposes

2. On-site testing of reinforced structures.

3. Drilling and core cutting

4. Conformity check of new buildings

5. Investigations on unknown structures

6. Corrosion analysis

How does the Cover meter Test Device Work?

A cover meter is a device that gives information about concrete covers and steel reinforcement in concrete using magnetic fields. Magnetic instruments for locating reinforcement steel (present within the concrete) work on the principle that the steel affects the alternating magnetic field. When a hand-held search unit is moved along the concrete surface, a beep indicates that the unit is located directly above a reinforcing bar. These meters can also be used to estimate the depth of a bar if its size is known, or estimate the size of the bars if the depth of cover is known. However, detailed calibration is needed to get satisfactory results. The bars may be located within 175 mm of the concrete mass but the method is not effective in heavily reinforced sections, sections with two or more adjacent bars or nearly adjacent layers of reinforcement. Inaccurate results may occur when the depth of concrete cover is equal to or close to the spacing of the reinforcing bars. During this test, steel or other metals must not be present close to the area under examination. Some results from tests must be calibrated by chipping of concrete to confirm concrete cover and bar size. A number of pachometers are available that range in capability from merely indicating the presence of steel to those that may be calibrated to allow the experienced user a closer determination of depth and the size of reinforcing steel.

Precautions

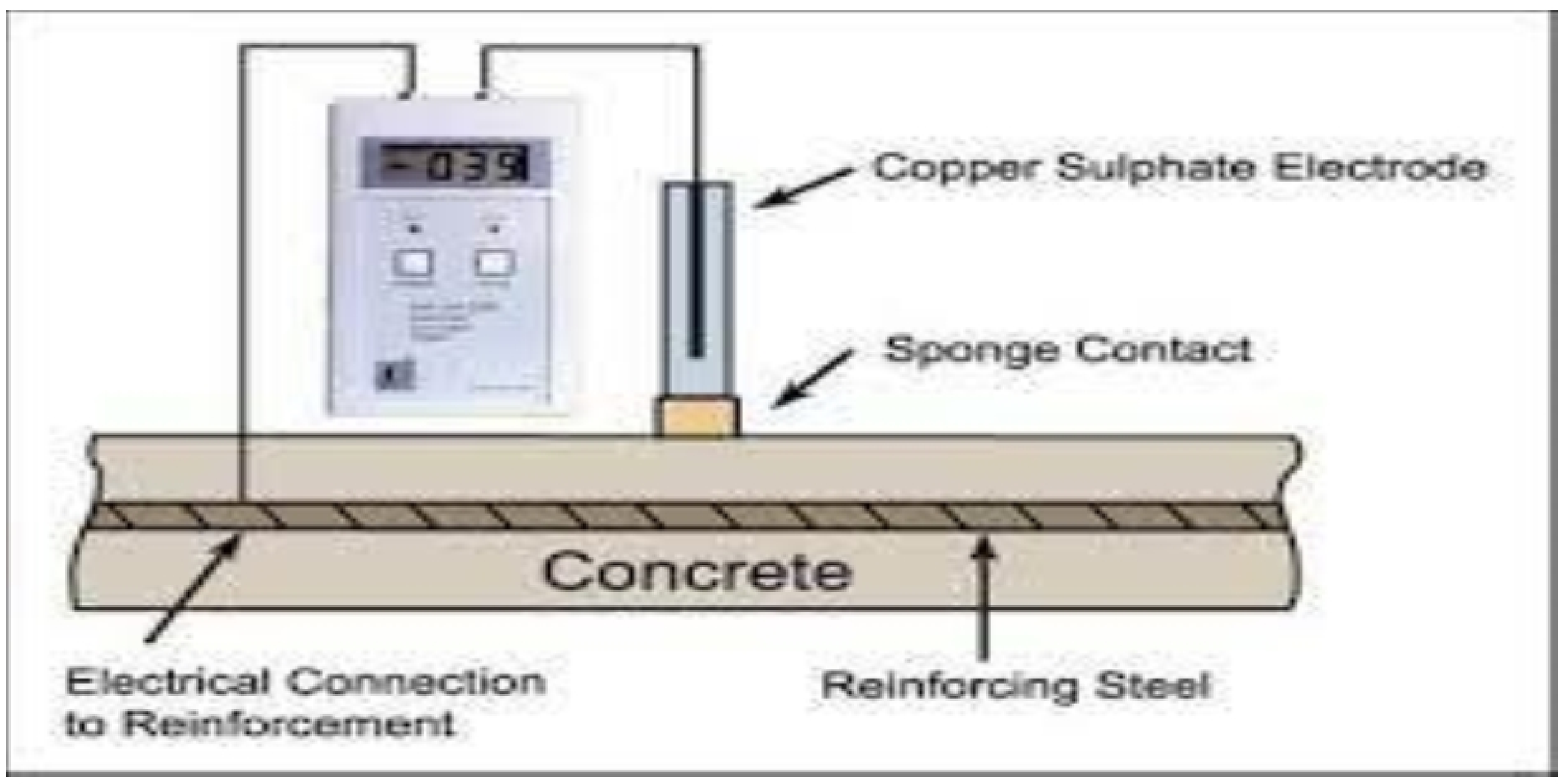
1. When the element is reinforced with two layers of steel bars, it is recommended to start the location with the first layer. The location of the second layer cannot be determined easily provided the layers are too close to each other.

2. It is recommended to select a place on the structure where there is sufficient spacing between the rebar's in order to determine the diameter of bars precisely.

3. It should be noted that the accuracy of cover meter test devices reduces as the concrete cover increases.

5. HALF- CELL POTENTIAL METER

The half-cell potential test is the only corrosion monitoring technique standardized by ASTM. It is used to determine the probability of corrosion within the rebar in reinforced concrete structures. This blog dives into the specifics of concrete corrosion, the half-cell potential technique for testing concrete corrosion, and the ways in which the data from the half-cell potential test can be interpreted The Basics of Concrete Corrosion In reinforced concrete structures, there is a natural protective film that forms on the surface and prevents the bar from corroding. With time, chlorides (from de-icing salts or marine exposure) and/or CO2 penetrate the concrete and breakdown that protective layer. Chlorides destabilize the passive film leading to its localized breakdown, while CO2 lowers the pH of the concrete below the level of stability of the passive film. In the presence of oxygen and water, an electrochemical reaction initiates the process of corrosion. Corrosion can be illustrated as shown in Figure 1, where the metal (rebar) reacts in the solution (available in the concrete pores) and gives away electrons from the anode (where oxidization occurs) to the cathode (where reduction occurs). The positive ions formed at the surface of the anode will react and create corrosion by-products. This electrochemical reaction creates a potential difference, and consequently a corrosion current, between the anodic and cathodic areas at the surface of the steel reinforcement. This current, or the potential distribution on the reinforcement surface, is what is of interest when measuring half-cell potential.



The Half-Cell Potential Technique

The schematic in Figure 2a represents a cell where each side is referred to as a half-cell. Each half-cell is represented by an electrode in a solution (electrolyte) and both half-cells are connected together. Since one of the electrodes has a higher tendency to corrode compared to the other, that electrode (anode) will oxidize and in turn will donate electrons. To keep the system in equilibrium and balance the charges in the electrolytes, there will be an exchange of ions through the salt bridge. The voltmeter will measure the potential difference (voltage) between both electrodes, which indicates the rate of dissolution of the anode.

To apply this concept to concrete and to interpret the results of corrosion potential, a reference electrode with a known potential is needed. Typically, for reinforced concrete applications, a copper/copper sulfate electrode (Cu/CuSO4) or silver/silver chloride electrode (Ag/AgCl) is used for the half-cell reference. This reference electrode is connected to the other half-cell represented by the embedded rebar. By connecting that reference electrode to the reinforcing steel and placing the reference electrode on the surface of the concrete, it is possible to measure the potential difference between the two half-cells.

ASTM C876 provides a guideline on how this measurement can be undertaken, and the relationship between the measured potential values and the corrosion probability. Interpretation of the result is qualitative and is based on the copper sulfate electrode (CSE). Table 1 shows the general interpretation guideline proposed by ASTM, where the measured potential ranges are categorized in three categories; more than 90% chance, less than 10% chance or an uncertain chance of corrosion.

Table 1: Relationship between the potential values and corrosion probability (adapted from ASTM C876)

Measured Potential(mV CSE)	Probability of steel corrosion activity
>-200	Less than 10%
-200 to -350	Uncertain
<-350	More than 90%

Interpreting Half-Cell Potential Data

At first glance, this test method seems very simple and comprises of the following steps:

1. Identify rebar location

2. Make a connection with the reinforcement (more than one connection can be required if there is a discontinuity between reinforcements)

3. Prepare concrete surface through wetting.

Measurements are quick as potential values only take a few seconds to stabilize before the next measurement can be taken. However, there are important limitations in terms of data interpretation that need to be taken into consideration.

The effect of the concrete condition (dry or wet), presence of chloride, absence of oxygen at the rebar surface (due to saturation), cover thickness, concrete resistivity, and temperature are all factors that can influence the results by shifting their potential reading towards a more positive or negative value as shown in Table 2. This can make the data interpretation challenging when using the guidelines given in the ASTM C876 (Table 1), especially around the uncertain measurement ranges.

Table 2: Typical ranges of half-cell potentials of rebar in concrete (adapted from RILEM TC154, 2003)

Conditions	Potential values (mV/CSE*)
Humid, chloride free concrete	-200 to +100
Wet, chloride contaminated concrete	-600 to -400
Water saturated concrete without oxygen	-1000 to -900
Humid, carbonated concrete	-400 to +100
Dry, carbonated concrete	0 to +200

Dry concrete	0 to +200

In addition, half-cell measurement is considered to be a zonal measurement as it will take an average potential measurement of the surroundings. An example is illustrated in Figure 3, where the measured potential will show sort of an average over a certain distance and where the actual location of the corroded bar can be challenging to distinguish, even with corrosion potential mapping.

6. CORROSION RESISTIVITY METER

The measurement of the resistivity of concrete gives an indication of the possibility of risk of the existence of significant levels of reinforcement corrosion. Corrosion of steel reinforcement within a structure will occur if sufficient chloride is able to penetrate through the concrete and depassivate the steel. If this occurs the reinforcement potential will decrease to approximately -350mV and lower as corrosion progresses. The rate of corrosion then becomes increasingly related to both the resistivity of the concrete and the rate at which oxygen can reach the steel. In general it has been shown that the lower the resistivity the greater the risk of corrosion, and when the value of the half cell potential indicates that corrosion is occurring this may be stated empirically as follows: Values greater than 12000 ohm.cm indicates that a significant rate of corrosion is unlikely. 5000 to 12000 ohm cm indicates that a significant rate of corrosion is almost certain.

Equipment Used

The equipment used consists of four 6mm diameter steel probes which are pressed onto the surface of the concrete using colloidal graphite as a contact medium. Each probe is provided with a terminal connection from which wires lead to an earth resistance meter. A current is passed between the two outer probes and the voltage between the two inner probes is measured by the meter which calculates and displays the resistance directly.

Method of Test

The test procedure is adapted from the Wenner Method for the measurement of the resistivity of soils. A check is made using a cover meter to ensure that no reinforcement is in the immediate vicinity (nearer than about 20mm to the surface). The four 6mm diameter steel pins are then coated with colloidal graphite, pressed onto the surface and connected to the earth resistance meter. Readings of resistance are directly read from the instrument. The resistivity of the concrete (r) is related to the measured resistance (R) by the formula $r = R2\pi a$ where r is the resistivity in ohm cm, R is resistance in ohms and a is the separation of electrodes in cm.