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Report Title

Non_Destructive Testing Techniques for Assessing Reinforced Concrete Structures, A Review

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ABSTRACT

The most popular non-destructive testing (Non-Destructive Testing) techniques for concrete structures as applied by the structural engineering sector are reviewed in this work. The foundations of nondestructive testing (Non-Destructive Testing) methodologies are examined with respect to their possibilities, constraints, methods of inspection, and interpretations. The elements influencing

The effectiveness of Non-Destructive Testing procedures is examined, and suggestions for mitigating their impact are made. Standard recommendations are offered for the implementation and interpretation of the Non-Destructive Testing techniques under discussion. It was discovered that Non-Destructive Testing of concrete is becoming more and more popular as a way to assess the strength, homogeneity, longevity, and other characteristics of current concrete constructions.

The belief that Non-Destructive Testing was inadequate was a result of a lack of knowledge regarding the materials used in construction and the Non-Destructive Testing procedures themselves. By identifying and outlining the most popular and effective Non-Destructive Testing techniques used on concrete buildings, this study aims to allay these worries.

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1 Introduction

According to ((Workman, 2012)), non-destructive testing (Non-Destructive Testing) is the process of examining, testing, or assessing materials, assemblies, or components without endangering the part's or system's capacity to function. Non-Destructive Testing is used to assess the quality and integrity of materials, parts, or assemblies without compromising their capacity to carry out their intended purposes. It is important to distinguish between non-invasiveness and non-destructiveness. Testing procedures that include intrusive measures but do not compromise a system's or part's future utility are deemed non-destructive.

One popular Non-Destructive Testing technique, for instance, is coring, which is used to remove and examine specimens from concrete components in order to ascertain the characteristics of in-situ concrete. Corring modifies the component's look and has a negligible impact on its structural integrity. When executed appropriately, coring preserves the structural component's use and is therefore regarded as non-destructive.

In order to ascertain a material's mechanical qualities, including its yield strength, compressive strength, tensile strength, ductility, and fracture toughness, destructive testing investigates failure processes. Non-Destructive Testing techniques investigate property indicators without identifying component or assembly faults. Many attempts and developments have been made to create NDT techniques that can reveal a material's mechanical, acoustical, chemical, electrical, magnetic, and physical characteristics. Acoustic tap testing was used in the 19th century to identify fractures in train wheels, which is one of the first recorded instances of nondestructive testing (Non-Destructive Testing) ((Stanley, 1995)). In recent years, a wide range of more sensitive, dependable, and quantitative NDT techniques have been developed.

The requirement for structural damage prevention and detection led to the development of NDT techniques.
Safety and economy are the main drivers for the widespread usage of NDT. New in-site testing methods have been developed to evaluate concrete at the building, commissioning, and maintenance phases of a structure's lifetime, in an effort to prevent the issues linked to structural deterioration.

A non-destructive survey's effectiveness is primarily determined by its depth of penetration, vertical and lateral resolution, contrast in physical characteristics, signal-to-noise ratio, and the amount of preexisting structural knowledge (McCann & Forde, 2001).

For any NDT approach to be successful, it is essential to comprehend material characteristics and the major problems related to its application in structural engineering. The following are the stages to choose a suitable NDT technique ((shull, 2002)):

knowing the physical characteristics of the material property or discontinuity that has to be examined.

knowing the fundamental scientific principles that underpin the NDT technique.

Recognizing the physical characteristics of the interaction between the test material and the probing field.

Recognizing the possible limits of the NDT technology now in use.

Considering regulatory, environmental, and economic considerations.

The civil and structural engineering sectors employ a broad variety of nondestructive testing (NDT) techniques.

Despite the seeming abundance of technical literature on nondestructive testing (NDT) of concrete, civil engineers, NDT researchers, and experts do not collaborate well. By defining and outlining the most popular NDT techniques used on concrete buildings, this study aims to close the gap.

2 NON-DESTRUCTIVE TESTNG METHODS TYPE

2-1 Surface hardness methods

Non-destructive surface hardness methods are non-invasive techniques used to examine a material's strength qualities. Concrete surface hardness techniques fall into two categories: indentation methods and rebound methods. These techniques aim to take advantage of empirical relationships between concrete strength characteristics and surface hardness as determined by rebound or indentation. In the field of civil engineering, indentations methods—which date back to 1930 ((jones, 1969))—are no longer widely used, but rebound methods are often used to examine the strength properties of concrete in relation to accepted testing and interpretation recommendations.

The typical rebound hammer test is the most widely used surface hardness method. The test, also known as the Schmidt Rebound Hammer, was created in 1948 by Swiss engineer Ernst Schmidt ((kolek, 1969)). Following impact with the concrete surface, the rebounded hammer records a rebound number. This number indicates the strength attributes of the concrete by referencing empirically proven relationships between the concrete's flexural and compressive strengths.

The basic knowledge of impact and rebound is connected to the wave propagation theory. When the plunger (σi) disturbs the concrete's surface, a compression wave is generated. A reflected compression wave is propagated via the plunger (σr) by the reaction force. According to((Akashi, 1984)study, the ratio of wave amplitudes (σr/σi) is shown to be proportional to the rebound number, which may be experimentally linked to compressive and flexural strength.

Compared to other NDT techniques, using the Standard Rebound Hammer needs fewer mechanical abilities. To find a smooth surface that is appropriate for testing, a visual inspection of the concrete surface should be done beforehand.

Calibration charts are used to lessen the various effects of gravity in whatever direction that the test is done in (Fig. 1). The plunger strikes the surface and bounces back a distance indicated by a sliding indicator when the hammer is forced up against the concrete until a spring-loaded mass is released (Fig. 1). The rebound number is the name given to the observed distance.

The manufacturer offers empirical correlations to link the rebound number to attributes of concrete strength; however, the manufacturer's testing settings may differ from the actual conditions. As a result, it is advised to carry out a test-specific correlation technique in which a number of concrete cylinders with varying strengths are ready for testing using a compression-testing equipment as well as a standard rebound hammer. The outcomes of the two tests are then combined into a straightforward regression analysis model, and using ordinary least squares, this model produces an empirical correlation. The standard rules that govern the standard rebound test's use and interpretation are presented in the publications below:

ASTM C 805: Standard Test Method for Rebound

Number of Hardened Concrete.

 BS EN 12504-2:2012: Testing Concrete in Structures

- Non-destructive Testing – Determination of Rebound Number.

An quick, affordable, and straightforward way to measure the strength qualities of concrete is to use the Standard Rebound Hammer. Nevertheless, a number of variables, including the concrete's smoothness, geometric characteristics, age, and internal and external moisture conditions, as well as the kind of coarse aggregate, cement, mold, and carbonation of the surface, influence the test's outcomes ((malhotra, 2004)). 15% to 20% accuracy is attained when estimating strength using rebound readings of specimens that resemble specimens from correlation curves (Concrete Institute of Australia, 2008).

Therefore, rather than being utilized in place of regular compression testing, it is advised to employ the usual rebound hammer test to assess the variability of strength attributes amongst concrete samples.

Fig 1 Surface hardness methods

2-2 Penetration resistance method

Through the use of previously known correlations, penetration resistance techniques are intrusive nondestructive testing procedures that investigate the strength qualities of concrete.
With these techniques, probes are pushed into concrete samples with a constant force. By using correlations, measuring the probe's depth of penetration yields information on the compressive strength of the concrete.
Despite the concrete being disturbed during penetration, the tests are regarded as non-destructive since the impact of the penetration resistance techniques on the structural integrity of the probed sample is negligible.

The Windsor probe system is the penetrating resistance technique that is most frequently employed. The device is a powder-actuated cannon that uses a depth gauge to measure the penetration distance of hardened allow-steel probes as it pushes them into concrete samples (Fig. 2). Standard standards for the application and interpretation that control penetration testing are presented in the publications below:
The standard test method for testing the penetration resistance of hardened concrete is ASTM C 803-202; recommendations for testing concrete using near-to-surface testing are outlined in BS 1881-207 Testing Concrete.

The near-surface concrete fractures and is crushed as a result of the dynamic forces created by the Windsor probe's penetration (Fig. 2). Upon penetration, a cone-shaped zone that includes fracture and is resisted by the nearby concrete's compression forms. Although the resistance and probe penetration depth are objectively associated, manufacturers' empirical connections frequently provide disappointing results. Thus, in order to get more reliable correlation charts, test-specific correlation operations should be carried out using penetration methods and compression-testing machines.

According to (malhotra, 2004) the variables that affect within-test variability include aggregate size, heterogeneous concrete, equipment error, and operator error. Aggregate size is the most important factor influencing within-test variability. For instance, testing samples with an aggregate size of 20 mm is predicted to have a 5% coefficient of variation; samples with an aggregate size of 55 mm are expected to have a 14% coefficient of variation (Concrete Institute of Australia, 2008). However, there are little to moderate variances in the projected early strength of concrete, which offers a respectable level of precision and assurance for formwork removal in concrete structures.

In addition, compared to other NDT techniques such surface hardness methods, there are less causes causing within-test variability. The Windsor probe system is easy to use, affordable, and rapid. The penetration resistance techniques must be used to examine the variability of strength attributes between concrete samples since, similar to surface hardness methods, they do not produce absolute values of strength.

Fig 2 Penetration resistance method

2-3 Pull-out resistance methods

Pull-out resistance techniques quantify the amount of force needed to remove common implanted inserts from the concrete surface. The force needed to remove the inserts yields an approximation of the strength qualities of concrete based on recognized relationships. The two kinds of pull-out techniques are defined by the two kinds of inserts: cast-in and fixed-in-place. For cast-in testing, the fresh concrete must have an insert placed inside of it before the concrete is placed. Less planning is needed for fixed-in-place tests, which entail inserting an insert into a drilled hole in solidified concrete.

Pull-out resistance techniques are intrusive but non-destructive techniques that are frequently used to measure the compressive strength of concrete.

The LOK test, created in 1962 by Kierkegaard-Hansen, is the most widely used pull-out test technique ((-hansen, 1975)). To ensure adequate testing of concrete with coarse particles, the test necessitates a 25 mm insert embedment . The term "lok-strength" refers to the force needed to remove the insert; in other pullout resistance systems, it is known as the pull-out force.

The standard criteria for pull-out resistance testing are provided by the publications listed below: BS 1881-207 Testing Concrete - Recommendations for the evaluations of concrete strength by near-surface tests; ASTM Standard C 900-13a: Standard Test Method for Pullout Strength of Hardened Concrete.

Shear and normal stresses acting on the insert surface oppose the pull-out force. Uncertainty in the knowledge of the concrete failure process is caused by the non-uniform three-dimensional condition of stress. In an effort to comprehend the underlying failure process, analytical and experimental research have presented significant correlations between compressive strength and pull-out force (Bickley, 1982; Keiller, 1982). It was discovered that the pull-out test's average coefficient of variance was around 8% (Carino, 2004).

Maximum aggregate size, cement mortar %, insert kind, and embedment depth are the variables that impact the variability of the results (Concrete Institute of Australia, 2008).

2-4 Pull-off resistance method

The pull-off test measures the tensile force needed to pull a disc that is adhered to the concrete surface using polyester or epoxy glue. It is a method used to evaluate the in-situ strength of concrete. Using proven empirical correlation charts, the pull-off force indicates the tensile and compressive strength of concrete.

The 007 Bond Test is the pull-off test that is most frequently utilized. A hand-operated lever, bond discs, an adjustable alignment plate, and force gauges make up the test (Fig. 3). A strong adhesive is used to adhere the disc to the concrete surface, and a screw is used to secure it to the lever that is manipulated by hand. Tension force is applied by the lever and measured by the force gauge once the movable alignment plate has been leveled (Fig. 3).

Using previously known empirical correlations, the pull-off tensile strength—which is computed by dividing the tensile force at failure by the disc area—is used to derive the compressive strength of concrete. Standard procedures for pull-off resistance testing are provided in the publications listed below:
BS 1881-207: Testing Concrete - Recommendations for the evaluations of concrete strength by near-surface testing; ASTM D 4541-109e1: Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.

Pull-off test techniques' primary benefit is its simplicity, speed, and adaptability to a variety of building environments. One important restriction is the adhesive's drying period, which is typically around a day. Another drawback is the possibility of human mistake in surface preparation leading to adhesive failure.

According to the Concrete Institute of Australia (2008), the tensile strength readings are frequently within 20% of the genuine tensile strength. According to Henderson, Basheer, and Long (2004), the size and kind of coarse particles are the main causes of the diversity in the results. To improve confidence via repeatability, it is advised to create correlation charts using samples that correspond to the testing circumstances and to perform the test many times using various disk sizes.

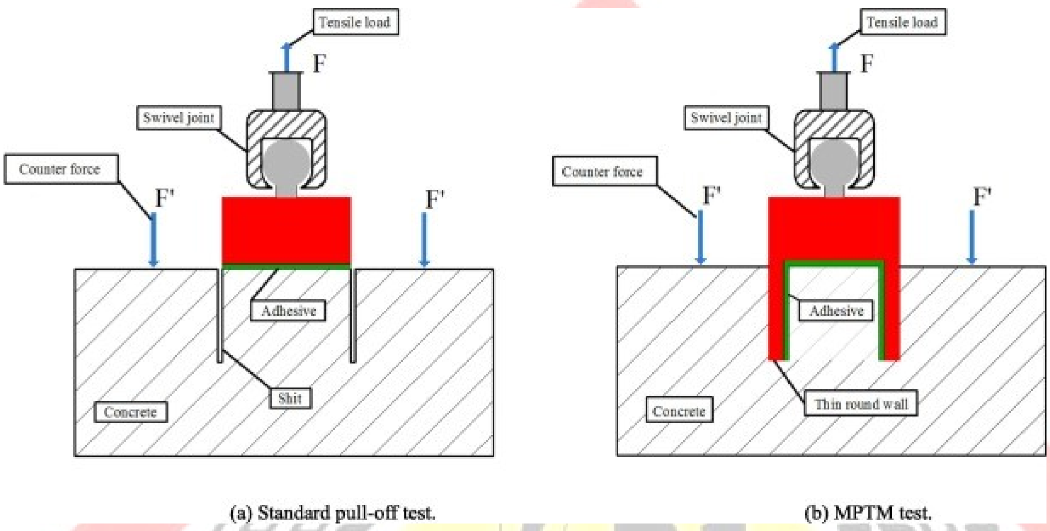

fig 3 Pull-off resistance method

2-5 Maturity test method

An NDT approach called the maturity method uses the temperature history recorded throughout the curing process to calculate the strength growth of concrete. The effects of temperature and time are quantified using the maturity function that is given. The strength of concrete is then ascertained using the obtained maturity factor in conjunction with recognized relationships. The maturity technique can be used for posttensioning and formwork removal in concrete construction, among other things.

Thermocouples are put into fresh concrete to measure temperature vs time (Fig. 4). A maturity index that offers a trustworthy estimation of early age concrete strength as a function of time may be calculated using the measured time history (Saul, 1951). ASTM C 1074-11: Standard Practice for Estimating Concrete Strength by Maturity technique is the standard guideline for testing and interpreting the maturity technique.

The Concrete Institute of Australia (2008) states that the water-cement ratio, curing temperature, cement characteristics, and aggregate qualities are the elements that cause variability in testing. To create the suitable maturity function while limiting the influence of the aforementioned elements, laboratory testing on concrete samples with similar characteristics must be conducted before attempting to predict the in-situ strength of concrete. To measure a temperature that is indicative of the entire concrete section, temperature probe sites need to be carefully chosen.

Fig 4 Maturity test method

2-6 Permeation test method

The primary reason for concrete degradation is the penetration of hostile chemicals into the concrete.

In order to determine how long concrete constructions would last, permeability is the dominating characteristic.

Non-destructive testing techniques called penetration tests are used to gauge the near-surface transport characteristics of concrete. Concrete permeability may be measured in three different ways: hydraulic permeability, which measures how well water moves through the material; gas permeability, which measures how well air moves through the material; and chloride-ion permeability, which measures how well electric charge moves through the material.

By means of proven correlations, the most widely used non-destructive approach for determining the permeability of concrete is the measurement of chloride penetrability. ASTM C 1202: Standard Test Method for Electrical Indication of Concrete's Ability to Resist is the accepted standard for the application and interpretation of chloride penetrability. A standard-sized cylinder is coringed out of the in-situ concrete as part of the test. The sample is then cut to size, sealed on two sides with epoxy, submerged in water, and put in a split testing apparatus that has a sodium chloride solution and a voltage potential applied to it (Concrete Institute of Australia, 2008). Next, the location of the charge measurement through the concrete is determined.

- a value of between 100 and 1000 Coulombs represents low permeability.
- a value greater than 4000 Coulombs represents high permeability.

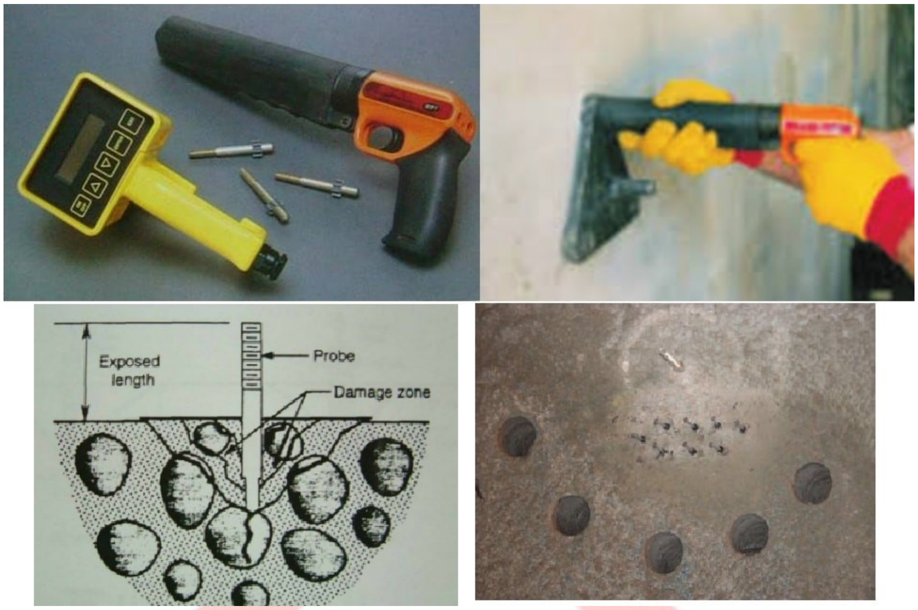

Fig 5 Permeation test method

2-7 Ultrasonic pulse velocity method

Ultrasonic pulse velocity techniques measure the time it takes for ultrasonic waves to travel from a sending point to a receiving location by propagating ultrasonic waves through solids. A material's composition, structure, elastic properties, density, and geometry may all be described by the characteristics of ultrasonic wave propagation through the application of mathematical relationships, previously established correlations, and recognized patterns.
Using this non-invasive method, faults in the material may also be identified and their degree of damage can be assessed by looking at how the ultrasonic waves disperse.

The conversion of a voltage pulse to an ultrasonic pulse and back via a transmitting and receiving transducer, respectively, is the fundamental process of ultrasonic pulse velocity techniques. An ultrasonic pulse is permitted to pass through the specimen medium via the transmitting transducer, which is positioned on the concrete surface. A receiving transducer at the other end detects the ultrasonic pulse after it passes through the concrete specimen and converts it to a voltage pulse (Fig. 6). It is

possible to calculate the wave pulse's velocity by knowing the separation between the two locations.
The ultrasonic pulse's velocity gives a thorough description of the material being studied.
The standard recommendations for ultrasonic pulse velocity testing are presented in the articles below:

ASTM C 597: Standard Test Method for Pulse Velocity Through Concrete;
 BS EN 12504-4:2004 Testing Concrete. Determination of Ultrasonic Pulse Velocity.
According to Naik, Malhotra, and Popovics (2004), the characteristics of the aggregate, the kind of cement, the water-to-cement ratio, admixtures, and the age of the concrete are the aspects that affect how variable ultrasonic pulse velocity techniques are when used to concrete. Furthermore, the measurements of pulse velocity may be significantly impacted by embedded reinforcement along the pulse route (Concrete Institute of Australia, 2008). Ultrasonic pulse velocity techniques are a great way to easily and affordably investigate the durability and uniformity of concrete by accounting for these aspects during the research process.

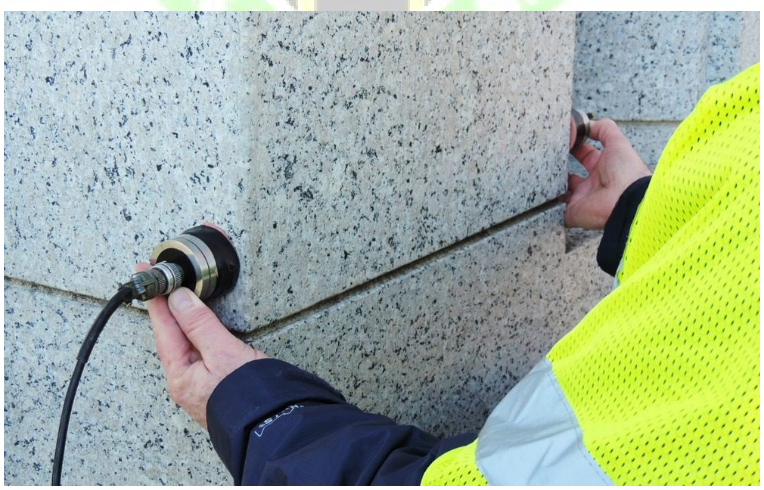

Fig 6 Ultrasonic pulse velocity method

2-8 Impact-echo method

A new advancement in ultrasonic techniques, the impact-echo system measures the thickness and integrity of concrete on a single surface. Additionally, the test is used to locate voids, cracks, and delamination. Its foundation is the observation of the surface motion of concrete following a brief mechanical impact. In particular, the test looks for concrete faults by measuring the amplitude of reflected shock waves.

The impact-echo system creates a brief ultrasonic stress wave pulse by the use of an electromechanical transducer, which then spreads into structures that resemble concrete plates. The stress pulse at their borders will be reflected by the various materials with varying densities and elastic characteristics. Returning to the transducer, which also serves as a receiver, is the pulse that is reflected. The received signal is shown on an oscilloscope, and the pulse's round-trip travel time is electronically calculated. The speed of the stress wave may be used to calculate the reflecting interface's distance.

ASTM C 1383 -04: Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method is the standard guideline for the use and interpretation of the impact-echo method. The kind and direction of the fault, its depth, and the impact's contact duration are the variables that influence the discovery of a flaw in concrete ((2001, p. cariano)). It turns out that the impact-echo approach works well for identifying a range of flaws in concrete buildings. Impact-echo test findings must be interpreted with expertise, as is the case with other procedures for finding flaws in concrete.

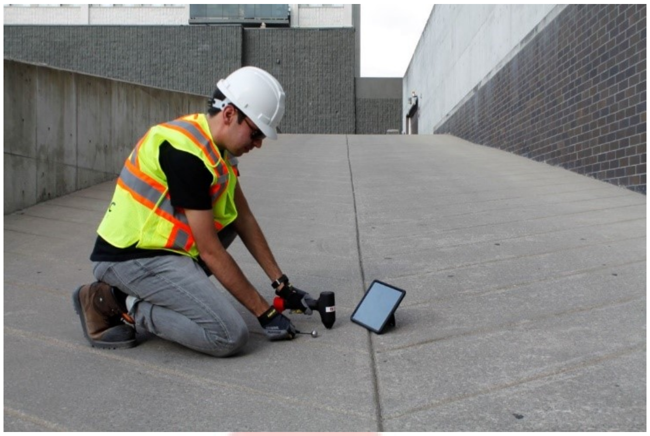

Fig 7 Impact-echo method

2-9 Corrosion of reinforcement method

Steel will always corrode owing to electrochemical and thermodynamic reactions that happen naturally as a result of iron's metallurgical properties.

Loss of passivation, the presence of moisture, and/or the presence of oxygen are necessary for the corrosion of steel reinforcement in concrete. These requirements are frequently met in concrete buildings, where the only ways to stop or slow down corrosion are by taking preventative actions. By using NDT, the distinct chemical, electrical, magnetic, and electrical characteristics of the resultant iron oxides might be used to gauge the degree of reinforcement corrosion.

To assess reinforcement corrosion non-destructively, high-impedance voltmeters and a half-cell system are needed (Fig. 8). By monitoring the resulting equipotential lines, this technique may identify the current flow of ion migration between anodic and cathodic sites across the concrete (Elsener, 1990)). Concrete serves as an electrolyte, and the observed potential difference that causes corrosion may be empirically connected to the corrosion risk.

ASTM C 876-91: Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete serves as the standard guideline for the application and interpretation of reinforcement corrosion testing. Exposure to the test environment and the electrical continuity of the reinforcement are prerequisites for successful testing. ASTM 876 states that there is

a 90% chance of active corrosion if the negative potential is greater than -350 mV,

a 90% chance of no corrosion if the negative potential is less than -200 mV, and

a 90% chance of corrosion uncertainty if the negative potential is between -350 and -200 mV.

The half-cell potential test is a useful technique to locate likely active areas of corrosion. It is recommended that potential surveys be supplemented with tests for carbonation and soluble chloride ion content for more accurate results.

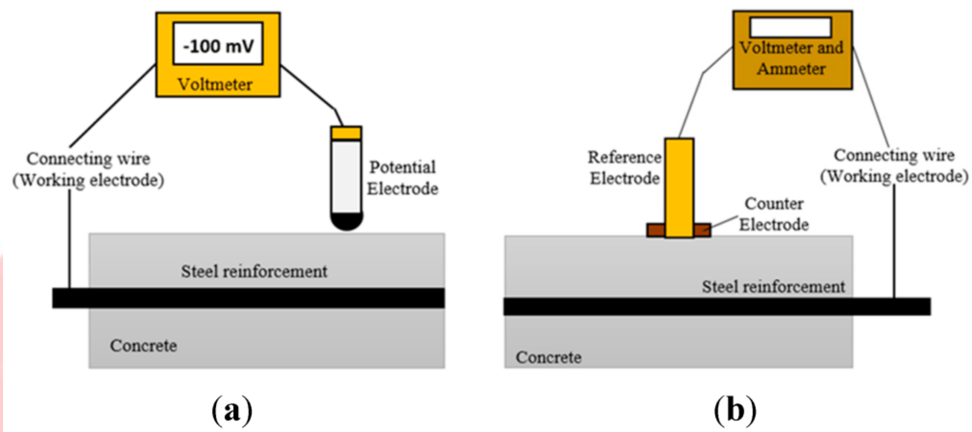

Fig 8 Corrosion of reinforcement method

3 FUTURE OF NON-DESTRUCTIVE TESTING

Innovations in sensors, creation of novel materials, and devices downsizing are all leading to the development of novel nondestructive testing techniques. In order to facilitate efficient data collection, processing, and interpretation of test parameters in respect to material integrity, data fusion approaches are being developed to integrate many nondestructive testing methodologies. The acoustic methods of nondestructive testing (NDT) have attracted a lot of commercial and research interest. This is the outcome of a discernible trend in which software employing sophisticated data analysis techniques processes acoustic waves in order to examine concrete constructions.

The use of NDT in concrete is becoming more and more common as a way to assess material integrity.

The adoption of non-destructive testing (NDT) is impeded by low knowledge of these procedures, which might be linked to a lack of comprehension of building materials and NDT techniques.

4 Discussion

An good method of assessing the strength of existing concrete structures without causing damage to them is through non-destructive testing of concrete. These tests let a structure to stand while an inspector assesses its strength and durability; hence, the building can continue to be occupied during the testing process.

5 Conclusion

Numerous non-destructive testing approaches have been examined in terms of their potential, restrictions, inspection methodologies, and interpretations.

The success aspects of non-destructive testing (NDT) procedures were investigated, and recommendations for mitigating their impact were made. It was discovered that most NDT techniques rely on matching measured parameters with known correlations. It was discovered that empirical correlations supplied by manufacturers frequently produced disappointing outcomes. For the NDT of concrete, test-specific correlation techniques should be carried out where appropriate.

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