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Non-Destructive Testing Techniques: A General Review of Methods

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Abstract:

This paper provides a general review of the NDT techniques, including what principle these methods work, their advantages, disadvantages, and limitations. NDT techniques are used worldwide in various industries like construction, oil and gas, and aerospace to evaluate the conditions of the structure and materials used in that structure without causing any damage to the structure. The methods covered in this paper are generally used in the construction industry, including tests for surface hardness and strength like rebound hammer, ultrasonic pulse velocity, core test, CAPO test, and some tests for corrosion assessment like half-cell potentiometer and carbonation test. A review of this paper aims to provide a comprehensive overview of the various NDT methods used in the construction industry and their role in ensuring the quality, safety, and reliability of structures and materials.

Keywords — **Rebound hammer, Ultrasonic Pulse Velocity, CAPO, Core, Half-cell potentiometer, carbonation.**

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I. INTRODUCTION

Concrete is the basic construction material. The strength of concrete should be so great that it can resist the load acting on it. In recent times we can only know about the mechanical properties of concrete by doing destructive testing on them. But with the advancement, we come across some non-destructive techniques that tell us about the quality of the concrete. We all know after placing concrete it comes under distress due to load or some other reasons. Due to this distress, its serviceability may be reduced. Also, we can say we have many tests to determine the mechanical properties of concrete before its use. Still, if we want to know the properties of concrete after its placing and also if want to see the condition of the structure already built we do some non-destructive test on it. We can't say that only a single NDT test can determine the condition of the present structure but we have to do three to four NDTs to determine the condition of the structure. After doing 3-4 tests we can get an idea of the present structure condition. After knowing the present condition of the structure we can know whether we have to rehabilitate the structure or rebuild or just do maintenance.

Need and Importance of Non-Destructive Test of Concrete:

It is very necessary to know about the properties of concrete in the hardened stage. NDT methods can be applied to both new and old structures. The non-destructive test is done for the assessment of concrete strength, any chemical attack on concrete, the corrosion potential of reinforcement in concrete, structure soundness (structural integrity), or any kind of fire damage or assessing the potential durability of concrete.

Benefits of NDT methods:

Ensure Safety: by checking flaws and defects in existing structures which may lead to severe failure in future.

Cost Saving: As we all know all structure deteriorates with time. Reasons for their d and

deterioration may differ but if we don't check the quality of structure or we say deterioration of structure in between from time to time then small deterioration may lead to severe damage. So if we repair the structure starting when we notice small damage then it may lead to cost savings in the future.

Preserves Structural Integrity: NDT methods didn't damage or alter the structural material, it only tested the quality of the structure and its performance and the structure or component of a structure is still in operational conditions which didn't affect the longevity of structures.

Quality Control: NDT techniques help in maintaining the quality of structure at all stages. It plays a crucial role in the satisfactory working and serviceability of the structures without causing any damage to the structure during tests from time to time.

Here are some statistical analysis studies about the significance of NDT techniques in the construction industry.

- A study by the American Society of Civil Engineers found that the use of NDT techniques can save up to 50% of the cost required for repairing and replacement of damaged structures.
- A study by the American Concrete Institute estimates that the use of NDT techniques in the construction industry can improve the quality of concrete structures by 25%
- One of the studies by the International Association of Bridge and Structural Engineers and Environmental Protection Agency says that the use of NDT techniques can increase the life span of bridges by up to 20 years and can reduce the impact of construction projects on the environment by up to 15%.

Some examples of NDT in action

- Inspection of the Golden Gate Bridge in San Francisco, California in 2019 was
- done by NDT techniques which revealed the various locations and areas of damage and deterioration which were later repaired.
- Delhi Metro Rail Corporation (DMRC) uses NDT techniques to inspect the conditions of rail tracks and hence ensure the safety of passengers.
- Mumbai Municipal Corporation uses NDT techniques to monitor the health and conditions of the structures near the coastal regions which helps in finding areas of damage and deterioration which are repaired latterly.
- India's Nuclear Power Corporation also uses NDT techniques like ultrasonic testing to inspect the condition of its critical component which further helps in ensuring the safety of power plants.
- NDT techniques are used by various sectors like the railway to inspect potential defects and ensure the safety of passengers.

II. LITERATURE REVIEW:

Here are some latest research and advancements in NDT Techniques

Morales Conde et.al. (2013) did a case study describing the applications of NDT techniques in the inspection of wooden roofs of historic buildings. According to their research use of NDT techniques which they use in their study can give a fair degree of accuracy in those areas of wooden structure which has deteriorated.

Sandeep Kumar Dwedi (2018) published a review paper entitled Advances and Researches in NDT in which he provides information about the various recent research and advances in NDT techniques to find defects in engineering material and construction. His paper majorly focuses on the scope of NDT techniques in composite material.

Kul Deep Sharma (2023) researched the analysis of NDT for improved inspection and maintenance strategies. He did a survey that was processed by 28 state agencies and the result obtained from his research was shown in tabular form which shows state agencies are more likely to use NDT techniques more likely for the bridge

superstructure and less for bridge sub-structure components.

S.Laguela et. al.'s (2012) paper entitled Automation of Thermographic 3D Modeling through Image Fusion and Image Matching Techniques new technique to inspect the building and find defects in construction without destructing.

III.DESCRIPTION OF NDT TECHNIQUES:

A] Test for determination of concrete strength

1. Schmidt Rebound Hammer Test:

This test measures the relative hardness of concrete at or near the surface. The unit of measurement in this test is the Rebound Number.

This test is used for

- strength assessment
- survey of delaminating concretes
- for the assessment of the relative strength of the structural members within the same structure.
- To detect the location of concrete with voids (weak concrete)

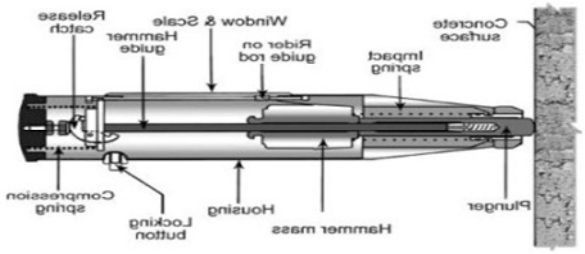

Figure1: Schmidt Rebound Hammer
Source: Internet

Principle "Rebound back of the spring mass is directly proportional to the hardness of the concrete surface on which it strikes."

The procedure to perform the test consists of various steps i.e.

Calibration of the hammer: calibration is done by performing a rebound test on an anvil provided by the supplier with the instrument. If the test will give reliable results provided by the supplier for the given anvil, the instrument is calibrated and ready for test.

Preparation of surface: The surface that is to be tested should be cleaned before the test. A rough surface will not give reliable results and hence be avoided. The test should be conducted away from the edges.

Testing by Rebound hammer: select the location where we want to find the strength. We have to make a grind of squares there. Then place the rebound hammer in particular squares of the grid and take different readings of the rebound number in different squares. Note down the rebound number.

Interpretation of result: The result is interpreted by the graph supplied with the instrument. The average rebound number is co-related to the surface hardness.

Average Rebound Number	Quality of Concrete
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated

Figure 2: Relation between rebound number and quality of concrete.
Source: Internet

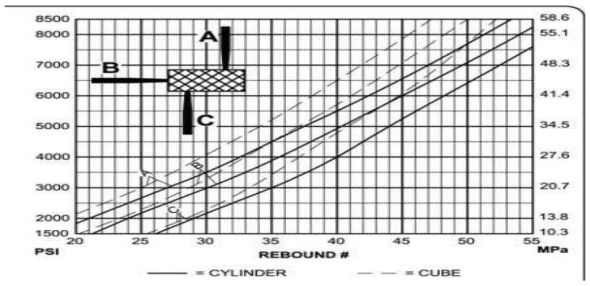

Figure 3: Graph showing the Relation between average rebound number and strength of concrete.
Source: Internet

Test can be conducted in any direction i.e. either horizontal or vertical. Hence result can be interpreted from the graph given in Figure 3 according to the direction shown in the graph i.e. A (vertically downward), B(horizontal), C (vertically upward).

Rebound hammers further of different types like type N, LR, L, etc. depending upon their suitability.

1.1 Advantages:

- Nondestructive test so no need for destructing the test sample.
- Provides quick results.
- Tells about the strength of the surface.

1.2 Disadvantages:

- If the surface is not prepared before the test, will not give reliable results.
- Results are unrelated to the interior properties of concrete as readings are taken on the surface.
- Result is affected by the surface conditions.
- Requires skilled labor
- Test is only limited to surface hardness.

2. Ultrasonic Pulse Velocity Test:

This test measures the travel time for an ultrasonic wave (50-54KHz) to pass from one face of a concrete surface to another i.e. measurable length of concrete medium between two faces that are under consideration.

The unit of measurement for this test is the velocity of ultrasonic pulse in km/sec

This test is used for

- Assessment of concrete quality and homogeneity, integrity of concrete
- Detection of the depth of the crack
- Assessment of poor compaction of concrete
- Detection of internal flaws in concrete
- Assessment of the strength of concrete in terms of quality
- Identify voids, honeycombing defects

The principle for this test is "that velocity taken by the ultrasonic wave to travel through concrete media tells us about the concrete quality in terms of homogeneity, integrity, and density." If the concrete has a high velocity that means concrete is of good quality in terms of homogeneity, and density, and concrete with lower velocities are indication of poor quality concrete.

Figure 4: Ultrasonic pulse velocity test
Source: Internet

This pulse velocity test consists of two ends i.e. one transmitter and the other is the receiver. The transmitter transmits the ultrasonic wave and the receiver end receives the wave. It gives the result in terms of velocity taken by the wave to travel from the transmitter to the receiver end and that velocity is related to concrete quality in the form of a table as given below:

Pulse Velocity(km /sec)	**Concrete Quality**
>4	Very Good to Excellent
3.5 to 4	Good to Very Good (Slightly porosity may exist)
3.0 to 3.5	Satisfactory (Loss of Integrity may exist)
<3	Poor (Loss of integrity exist)

Table 1
Source: Internet

Arrangement of transducer i.e. transmitter and receiver end can be done in following ways i.e.

Direct transmission (opposite faces)
Indirect transmission (same faces)
Semi Direct transmission (adjacent faces)

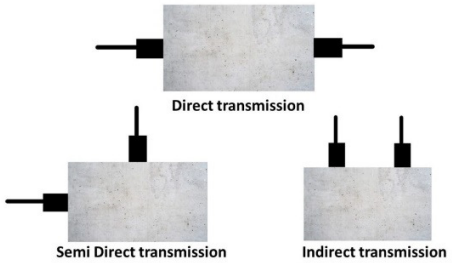

Figure 5: Various types of arrangement of transducer
Source: Internet

2.1 Advantages:

- Gives results quickly
- If properly used, then considerable information about the interior of concrete may obtained.
- It depicts the voids and defects in the concrete material.
- Also estimate the severity of deterioration.
- Can also evaluate the depth of the surface crack.
- By this test we can also determine dynamic Young's modulus of elasticity.\
- Instrument is portable.

2.2 Disadvantages:

- Does not give results directly in terms of strength, it only assesses the quality of concrete in terms of its integrity and uniformity.
- Surface conditions and placement of transmitter and receiver end may affect the accuracy of the test
- The presence of a steel bar influences the pulse velocity so it's necessary to know about the location of the steel bar before the test and hence not to use it to produce a pulse at that point.
- It cannot detect tiny defects and sometimes overestimates which will be questionable to its accuracy.

3. Rebar Locator Test (Profometer / Rebar Scanner):

Generally used for the detection and location of steel bars inside the concrete surface, to find the concrete cover by detecting the steel bar, or to determine bar diameter.

It works on the principle of magnetic field. It is the fastest and easiest way of detecting bars in concrete. It is used to find a safe spot before drilling to get the core sample.

This instrument is small and portable and is generally used along with the UPV test and core test. The instrument operates on battery and therefore can be used without electricity. Instruments have sufficient storage capacity to retain data.

The general procedure for the test consists of the following steps:

- Setup of the instrument.
- Calibration of instrument
- Preparation of surface by removing all dust and debris from the surface on which the test is to be performed.
- Make a grid or point location where we have to place a sensor.
- Then placement of the sensor on predefined lines or grid
- The sensor emits signals and emitted back signals are detected by the sensor giving information about bars.
- The display screen displays the data and data is recorded.
- Interpret the data and find the results.

3.1 Advantages:

- Quick method.
- Helps in assessing the location of reinforcement bars inside concrete structures.
- It helps in determining whether the cover meets the required standard or specifications or not by measuring the concrete cover.
- It has storage capacity which helps in storing data that can be further used to make reports.
- It can be used in different parts of a building like walls, slabs, beams, columns, etc.

3.2 Disadvantages:

- This test cannot detect very closely placed bars.
- This test only detects up to a certain depth.
- This test does not give an idea about the quality of reinforcement, hence unable to detect durability.
- Requires a skilled person.
- Results affected by humidity, and temperature.

Figure 6: Profometer Test
Source: Internet

4. Core Test:

It is a semi-destructive test and is used for the in situ determination of concrete compressive strength where concrete cube didn't give satisfactory results due to uncertain reasons and poor workmanship and sometimes also for the safety assessment of existing concrete. Concrete which is to be tested should be at least 28 days old.

In this method core of a specific measurement is drilled out or extracted in any direction either horizontal or vertical from concrete which is further tested for compressive strength. A minimum of three cores must be extracted from each location. The core is extracted employing a drilling tool with a diamond bit. The drilling tool is associated with a machine, these machines are heavy and should be firmly braced and supported so that the specimen which is extracted does not have distorted and broken ends. The core specimen that is extracted, doesn't have an even surface and the ends of the specimen are not plane and perpendicular to the specimen axis then to make their surface smooth, plane and even, we provide capping.

Figure7: Core Extraction
Source: Internet

According to [2], the core specimen length-to-diameter ratio is also determined by measuring the average length and average diameter (by taking an average of the two diameters of the cylindrical specimen). Depending upon the length-to-diameter ratio some correction factors are applied to the compressive strength as follows:

L/D (cylindrical specimen)	Correction factor
1.75	0.98
1.50	0.96
1.25	0.93
1.0	0.87

Table 2
Source: Internet

Before testing of specimen, the specimen should be placed in water at having temperature of 24°C to 30°C for 48 hours. The number of cores which is to be taken out depends upon the Engineer-in-charge of that area and also core extraction should not be done near joints or where there is reinforcement.

4.1 Advantages:

- Gives reliable results as compared to another test.
- Can assess the quality of concrete in terms of safety which is already placed.
- Also assess the strength of the concrete cube which didn't give satisfactory results due to poor workmanship or other reason.

4.2 Disadvantages:

- Need skilled labor for extraction of core and capping of specimen.
- Care should be taken for extraction of the core that reinforcing bars are not included in the core specimen.
- Results may vary if we don't use virgin samples.
- The test produces noise and vibration, the case if it is to be done near schools, or hospitals then proper measures should be taken.

5. Pull Out Test:

Generally, two tests come under this category CAPO Test/ LOK Test. Both tests are used for the assessment of concrete compressive strength. In both tests pull-out force is recordedand co-related to the compressive strength.

LOK Test takes 4-5 minutes for testing with pre-installed inserts whereas Capo test didn't require any pre-installed inserts. Initially, the CAPO test was designed to assist with the LOK test. The LOK test uses a disc cast into fresh concrete whereas the CAPO test uses a ring extended into the hole in existing concrete.

Generally, a test that is used most of the time is the CAPO test. CAPO stands for Cut and Pull Out test. Generally used for the assessment of the in-situ strength of the structures.

It works on the principle that the force required to pull out a steel disc/ring from a slot of 25mm diameter at a depth of 25mm from the surface of the concrete is the direct measure of its compressive strength.

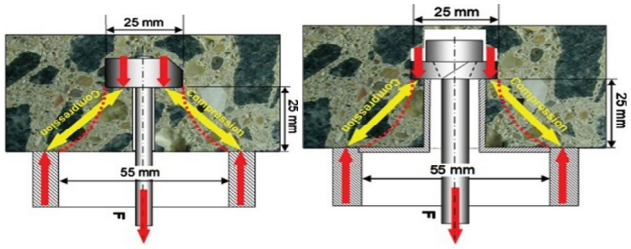

Figure 8: LOK Test & CAPO Test
Source: Research Article in IOS Press Content Library July 2024

This test gives results within 10-15 minutes. The results of this test are not influenced by surface properties like moisture content, texture, or hardness. There are some correlations between pull-out force and compressive strength from where we can find the compressive strength.

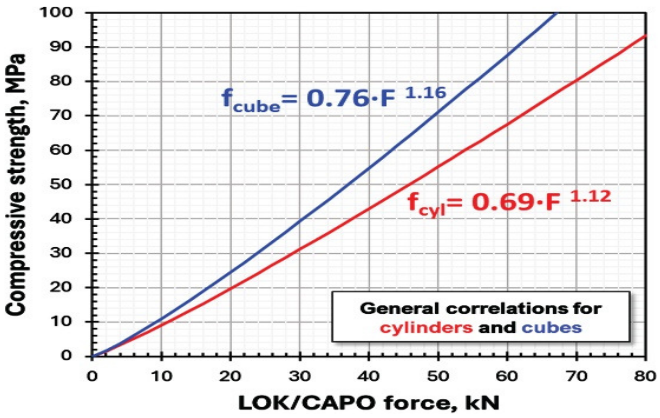

Figure 9: General Correlation between Pull Out force & compressive strength
Source: Research Article in IOS Press Content Library July 2024

General procedure for the test

- Firstly, the test location surface is ground and an 18.4mm hole is made perpendicular to the surface using a diamond core bit.
- Then a hole/slot of 25mm diameter at a depth of 25mm is made out.
- A split disc is extended in the slot and pulled out by using a pulling machine which reacts against a 55mm diameter counter pressure ring.
- Concrete which is in between the extended ring and counter pressure ring is in compression.
- Test continues till extended ring and inner pressure ring dislodged.
- In the end, the pull-out force recorded is co-related to the compressive strength.
- After the test, the hole left behind is first cleaned and then primed with epoxy glue and the hole is filled with polymer-modified mortar, and the surface is then smoothened.

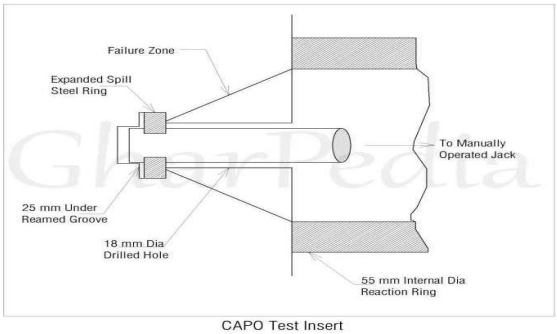

Figure 10: Different parts of the extended ring and counter pressure ring.
Source: Article in MidTech

The test will give more reliable results if our test specimen and compressive strength specimen are of similar size, consolidated to the same density, and cured under the same conditions.

5.1 Advantages:

- Gives reliable results as compared to other tests.
- Can assess the compressive strength of existing concrete and also for the assessment of structure serviceability.

5.2 Disadvantages:

- Not reliable in conditions where there is reinforcement mesh.
- Semi-destructive test.
- The test is done on small specimens therefore result may vary for real-world conditions.
- If the test is to be done on several specimens, then the test is time-consuming.

Hence above discussed test helps monitor the structure's health by assessing its strength and giving guidance for its repair and rehabilitation.

B] Test for corrosion in concrete:

1. Half Cell Potentiometer:

This test is used for the probabilistic assessment of corrosion in concrete. It works on the principle of establishing an electrical circuit between embedded reinforcing steel and a reference electrode of known potential generally copper – copper sulfate electrode and high impedance voltmeter.

In the whole circuit or cell, embedded steel is half-cell and the other half-cell is the reference electrode. The potential difference between the half-cell embedded steel and the half-cell reference electrode is measured which is connected to a voltmeter.

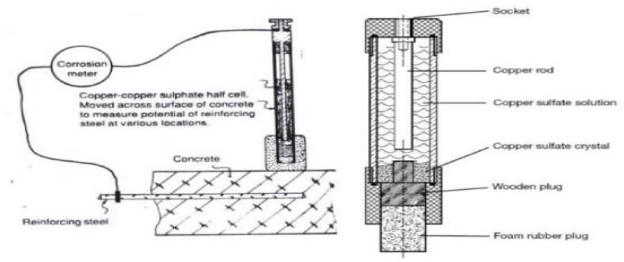

Figure 11: Half-cell potentiometer assembly
Source: Article in Construction Diagnostic

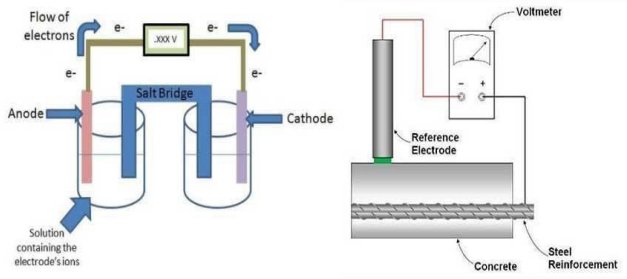

Figure 12: Half-cell potentiometer assembly
Source: Internet (Giatec)

Interpretation of the results is done by any of two methods i.e. by numeric magnitude technique or potential difference technique. In the potential difference method, which is generally used, we generally relate the potential difference with the probability of steel corrosion as given below.

Measured Potential Difference (mV CSE)	Probability of steel corrosion
>-200	Less than 10%
-200 to -350	Uncertain
<-350	More than 90%
<-500	Severe Corrosion

Table 3: Half-cell potentiometer assembly
Source: Internet (Giatec)

1.1 Advantages:

- It can assess the corrosion activity in embedded reinforcement in concrete.
- Test is cost-effective.
- The test is quick and easy to perform.

1.2 Disadvantages:

- It will not give reliable results on coated concrete surfaces
- Before performing the test, we mark grid spaces for placing electrodes where we have to find potential differences. If these grid spaces are wide, then it will not give proper results as it may leave the point where corrosion starts.
- Before the test, the concrete surface is wetted properly to make the circuit complete, if not proper stability is achieved then the test will not give proper results.

2. Carbonation Test:

This test helps in indicating corrosion in concrete surfaces. Carbonation in general terms, is the chemical reaction between the atmospheric carbon dioxide, calcium hydroxide, and hydrated calcium silicate in the concrete. Carbonation decreases the pH of concrete which leads to corrosion in embedded steel, ultimately resulting in cracks in concrete.

So if we find out carbonation test of any concrete is positive then it will indirectly indicate the corrosion of embedded reinforcement.

Carbonation is simply identified by spraying the core surface of the concrete with an indicator that tells about the loss of alkalinity. Generally, a phenolphthalein indicator is used. If the concrete core sample gives a dark pink color (magenta shade) then it indicates no loss of alkalinity and if no change in color, then there is a loss of alkalinity. A stable reading may be obtained after 5-10 minutes after spraying.

The chemicals used for the test is phenolphthalein (1% solution in diluted ethyl alcohol) mixed with methylated spirit to form a chemical indicator. One spray bottle is also used for spraying indicators on concrete surfaces.

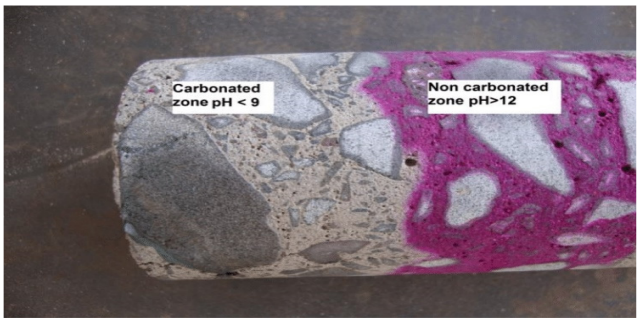

Figure 13: Showing carbonated and non-carbonated part
Source: Internet

Procedure for the test

- Measure 1 gram of phenolphthalein and mix it with 300 ml distilled water and 700 ml methylated spirit to form a 1 liter concentrated solution and put it in a spray bottle.
- Extract the core sample with any extracting instrument and then clean the sample by rinsing it with clean water to remove dust.
- Air dry the core sample.
- Then spray the solution on the surface of the sample after air drying using a spray bottle.
- Through visual inspection notice the color change of the core sample. If the core sample color changes immediately then it indicates no loss of alkalinity i.e. no carbonation and if the color doesn't change it indicates loss of alkalinity i.e. presence of carbonation.
- Then measure the colorless depth of the sample from both sides. The colorless depth of the sample is a measure of the extent of carbonation or carbonation depth.
- Carbonation depth should be measured on the exposed surface

Figure 14: Carbonation Depth measurement
Source: Internet

2.1 Advantages:

- Measuring the carbonation depth, gives a measure of the corrosion of reinforcement embedded in concrete.
- The test is cost-effective and easy to perform
- Test compliance with standards.
- Helps in assessing concrete quality.
- Can be used for the whole structure or for a particular area for determining the risk of corrosion attack.

2.2 Disadvantages:

- It only focuses on carbonation-induced corrosion no other type of degradation
- It requires a core sample, sometimes no samples are required when not getting proper results, which results in damage to the structure.
- Not suitable for those concretes which have specialized admixtures

Hence, half-cell potentiometer and carbonation depth test are essential tools for determining the durability of concrete structures and areas of high risk for repair and maintenance.

Before going to the test discussed above one should go through the codes given below for the complete information of the tests.

CODE	TEST NAME
IS 516(Part 5/ Section 1): 2018	Ultra Sonic Pulse Velocity Test (1st Revision)
IS 516(Part 5/ Section 2): 2021	Half Cell Potentiometer Test (1st Revision)
IS 516(Part 5/ Section 3): 2021	Carbonation Depth Test (1st Revision)
IS 516(Part 5/ Section 4): 2020	Rebound Hammer Test (1st Revision)
IS 516(Part 4): 2018	Core Test (1st Revision)
ASTM C900, BS 1881:207 or EN 12504-3	CAPO Test

Table 4

IV CONCLUSION:

The integration of NDT techniques in the construction industry offers a wide range of applications in terms of safety, cost-effectiveness, maintaining quality control, and ensuring structural integrity by detecting flaws and defects in structures without causing damage to the structure. The review highlights the various NDT techniques including the Rebound hammer test, ultrasonic pulse velocity test, rebar locator test, core test, and CAPO test defining their procedure, advantages, and, disadvantages.

These tests help the engineer and construction professional to know about the condition of the structure which helps in making decisions about repair, maintenance, and rehabilitation of the structures ultimately leading to sustainability and longevity of infrastructure. To fully utilize the potential of these techniques further research is needed to eliminate the limitation of these tests which will be a key focus of further investigations.

Some recommendations:

- NDT techniques should be integrated with the latest technologies to ensure and enhance the safety and efficiency of the test.
- Training about these NDT techniques should be given to all construction professional so that their applicability can be increased.
- Continuous research should be done on these techniques to eliminate the limitations of these techniques.

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