NDT: Diagnosing Anomalies in Concrete Structure Through Non Destructive Testing

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Importance and need of non-destructive testing

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination. Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring.

Basic methods for NDT of concrete structures

The following methods, with some typical applications, have been used for the NDT of concrete:

- Visual inspection
- Half-cell electrical potential method
- Schmidt/rebound hammer test
- Carbonation depth measurement test
- Permeability test
- Penetration resistance or Windsor probe test
- Cover meter testing
- Radiographic testing

- Ultrasonic pulse velocity testing
- Sonic methods using an instrumented hammer providing both sonic echo and transmission methods.
- Tomographic modeling
- Impact echo testing
- Ground penetrating radar or impulse radar testing
- Radioisotope Gauges

A brief of every test is outlined in upcoming paragraph's

Visual inspection

Visual testing is probably the most important of all non-destructive tests. It can often provide valuable information to the well trained eye. Visual features may be related to workmanship, structural serviceability, and material deterioration and it is particularly important that the engineer is able to differentiate between the various signs of distress which may be encountered. These include for instance, cracks, pop-outs, spalling, disintegration, colour change, weathering, staining, surface blemishes and lack of uniformity. An engineer carrying out a visual survey should be well equipped with tools to facilitate the inspection. These involve a host of common accessories such as measuring tapes or rulers, markers, thermometers, anemometers and others. Binoculars, telescopes, borescopes and endoscopes or the more expensive fibre scopes may be useful where access is difficult. Sketches of typical defects found by visual inspection are shown below:-

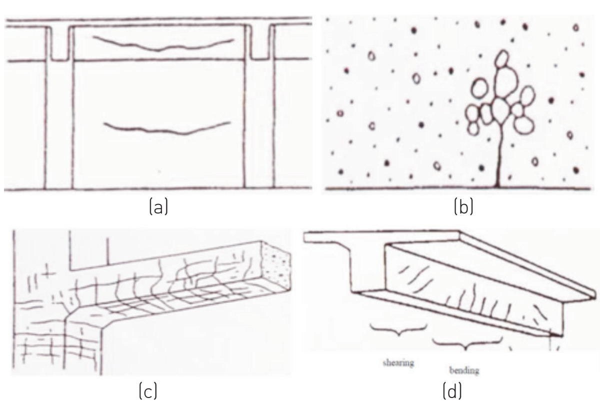


Figure 1 : (a) Sketch of crack due to concrete settling, (b) Sketch of exposed aggregate, (c) Sketch of effect of fire on concrete, (d) Sketch of cracks due to bending and shear stress

Half-cell electrical potential method

The method of half-cell potential measurements normally involves measuring the potential of an embedded reinforcing bar relative to a reference half-cell placed on the concrete surface. The half-cell is usually a copper/copper sulphate or silver/silver chloride cell but other combinations are used. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location may be related empirically to the measured potential difference. In some circumstances, useful measurements can be obtained between two half-cells on the concrete surface. ASTM C876 - 91 gives a Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete. The electrical half-cell potentials are recorded to the nearest 0.01 V correcting for temperature if the temperature is outside the range 22.2 ± 5.5oC. The schematic test setup is shown in Figure 2 below.

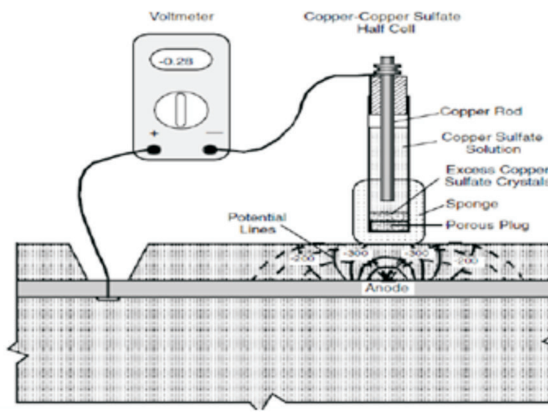


Figure 2 : The Schematic test setup of Half Cell Electrical Potential Method

The test data is represented in equipotential contour map: On a suitably scaled plan view of the member the locations of the half-cell potential values are plotted and contours of equal potential drawn through the points of equal or interpolated equal values. The maximum contour interval should be 0.10 V.

An example is shown in Figure 3.

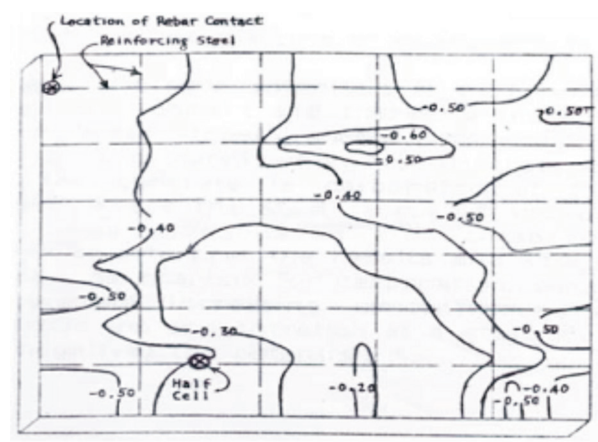
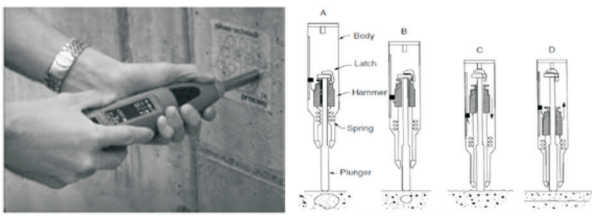


Figure 3 : Equipotential contour map

Schmidt/rebound hammer test

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number. Further, Kolek has attempted to establish a correlation between the hammer rebound number and the hardness as measured by the Brinell method. A typical Schmidt rebound hammer weighs about 1.8 kg and is suitable for use both in a laboratory and in the field (Refer Figure 4a). A schematic cutaway view of the rebound hammer is shown in Figure 4b.

The hammer can be used in the horizontal, vertically overhead or vertically downward positions as well as at any inter-



(a) (b)

Figure 4 : (a) Typical Hammer, (b) Typical schematic cutaway view

mediate angle, provided the hammer is perpendicular to the surface under test. The position of the mass relative to the vertical, however, affects the rebound number due to the action of gravity on the mass in the hammer. A typical comparison between correlation curves for crushed limestone and siliceous is shown in Figure 5 below.

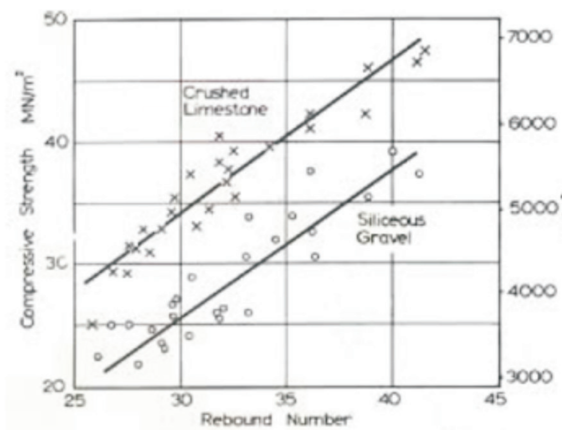


Figure 5 : Typical Compressive Strength versus Rebound Number curve

Carbonation depth measurement test

Carbonation of concrete occurs when the carbon dioxide, in the atmosphere in the presence of moisture, reacts with hydrated cement minerals to produce carbonates, e.g. calcium carbonate. The carbonation process is also called depassivation. Carbonation penetrates below the exposed surface of concrete extremely slowly. The time required for carbonation can be estimated knowing the concrete grade and using the following equation:

$$t = \left(\frac{d}{k}\right)^2$$

Where
t is the time for carbonation,
d is the concrete cover,
k is the permeability.

If there is a need to physically measure the extent of carbonation it can be determined easily by spraying a freshly exposed surface of the concrete with a 1% phenolphthalein solution. The calcium hydroxide is coloured pink while the carbonated portion is uncoloured. The only limitation of this test is the minor amount of damage done to the concrete surface by drilling or coring.

Permeability test

Permeability of concrete is important when dealing with durability of concrete particularly in concrete used for water retaining structures or watertight sub-structures. Structures exposed to harsh environmental conditions also require low porosity as well as permeability. Such adverse elements can result in degradation of reinforced concrete, for example, corrosion of steel leading to an increase in the volume of the steel, cracking and eventual spalling of the concrete. Permeability tests measure the ease with which liquids, ions and gases can penetrate into the concrete. In situ tests are available for assessing the ease with which water, gas and deleterious matter such as chloride ions can penetrate into the concrete. Three types of permeability test used frequently are Initial surface absorption test, Modified Figg permeability test, and In situ rapid chloride ion permeability test.

Penetration resistance or Windsor probe test

The Windsor probe, like the rebound hammer, is a hardness tester, and its inventors' claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe. The Windsor probe consists of a powder-actuated gun or driver, hardened alloy steel probes, loaded cartridges, a depth gauge for measuring the penetration of probes, and other related equipment. Various components of this test is shown in Figure 6(a). Typical Relationship between exposed probe length and 28 day compressive strength of concrete is shown in Figure 6(b) below.

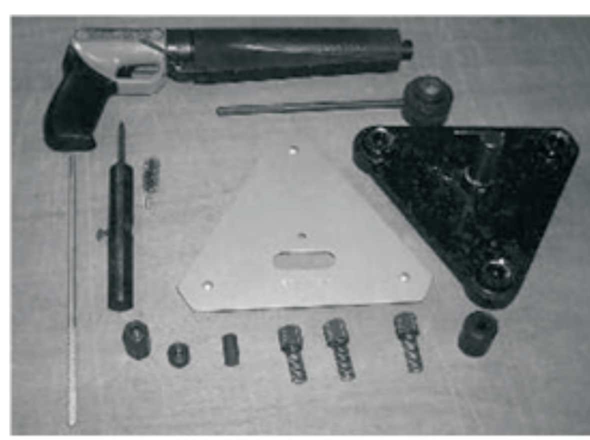


Figure 6(a) : Various Components of Windsor probe test

Radiographic testing

The intensity of a beam of X rays or gamma rays suffers a loss of intensity while passing through a material. This phenomenon is due to the absorption or scattering of the X or gamma rays by the object being exposed. The amount of radiation lost depends on the quality of radiation, the density of the material and the thickness traversed. The beam of radiation, which emerges from the material, is usually used to expose a radiation sensitive film so that different intensities of radiation are

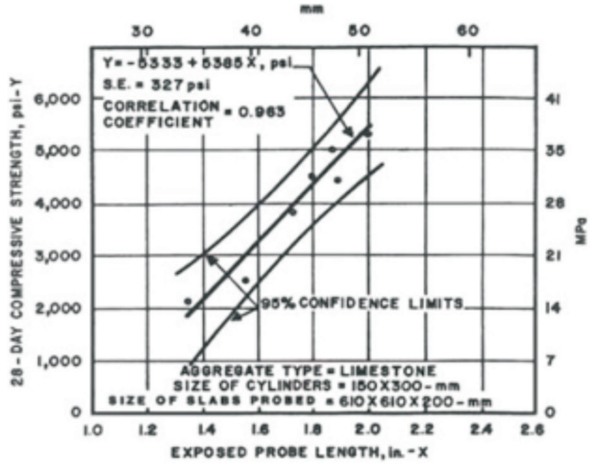


Figure 6(b) : Typical Relationship between exposed probe length and 28 day compressive strength

revealed as different densities on the film. The basic principle of radiography is shown in Figure 7.

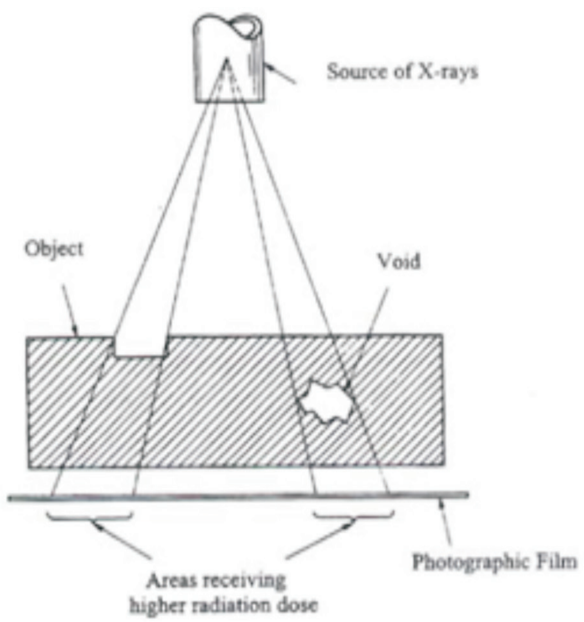


Figure 7 : Principle of radiography

Equipment used for radiographic testing includes primarily, X ray equipment & Gamma ray sources. Radiography can be used to locate the position of reinforcement bar in reinforced concrete and also estimates can be made of bar diameter and depth below the surface. It can reveal the presence of voids, cracks and foreign materials, the presence or absence of grouting in post tensioned construction and variations in the density of the concrete.

Ultrasonic pulse velocity testing

A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured.

Longitudinal pulse velocity (in km/s or m/s) is given by:

$$v = \frac{L}{T}$$

Where
v is the longitudinal pulse velocity,
L is the path length,
T is the time taken by the pulse to traverse that length.

The equipment for pulse velocity test consists essentially of an electrical pulse generator, a pair of transducers, an amplifier and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer. Measurement of the velocity of ultrasonic pulses of longitudinal vibrations passing through concrete may be used for the following applications:

- determination of the uniformity of concrete in and between members
- measurement of changes occurring with time in the properties of concrete
- correlation of pulse velocity and strength as a measure of concrete quality.
- determination of the modulus of elasticity and dynamic Poisson's ratio of the concrete.

The test apparatus and three arrangements for tranducer in this test is shown in Figure 8.

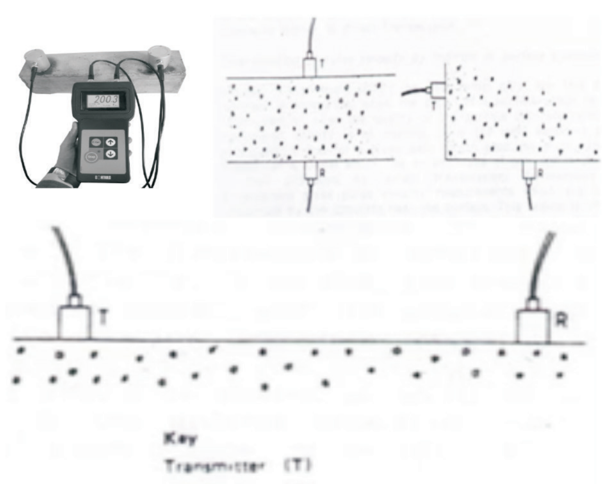


Figure 8 : Test Aparatus and Various transmission arrangement

Ground penetrating radar or impulse radar testing

Ground penetrating radar (GPR) is a non-destructive technique with a wide range of potential applications in the testing of concrete. It is gaining acceptance as a useful and rapid technique for non-destructive detection of delaminations and the types of defects, which can occur in bare or overlaid reinforced concrete decks. It also shows potential for other applications such as measurement of the thickness of concrete members and void detection.

Radioisotope Gauges

The use of radioisotopes for the non-destructive testing of concrete is based on directing the gamma radiation from a radioisotope against or through the fresh or hardened concrete. When a radiation source and a detector are placed on the same or opposite sides of a concrete sample, a portion of radiation from the source passes through the concrete and reaches the detector where it produces a series of electrical pulses. When these pulses are counted the resulting count or count rate is a measure of the dimensions or physical characteristics, e.g. density of the concrete.

Other Methods of NDT

Acoustic Emission

Acoustic emissions are microseismic activities originating from within the test specimen when subjected to an external load. Acoustic emissions are caused by local disturbances such as microcracking, dislocation movement, intergranular friction, etc.

Computer Tomography

Computer tomography (CT), also called computerized radioactive tomography, is the reconstruction of a cross-sectional image of an object from its projections. In other words, it is a coherent superposition of projections obtained using a scanner to reconstruct a pictorial representation of the object.

Strain Sensing

Strain sensing is commonly used to monitor the reaction of a structure or structural elements when subjected to load, e.g. during a full scale load test. It is also employed to monitor the behaviour or rate of deterioration of structures in service, like crack growth.

Partial destructive tests

In between NDT and Destructive test there is another category called Partial destructive test. Some of the commonly used partial destructive test is as mentioned below.

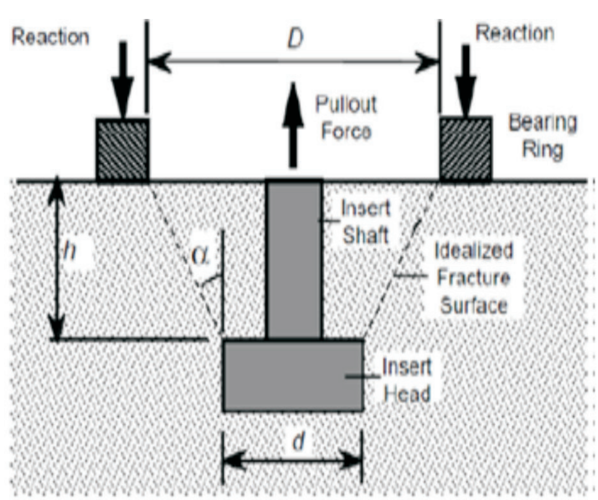


Figure 9 : Schematic representation of pull out test

Pullout test

The pullout test measures the force required to pull an embedded metal insert with an enlarged head from a concrete specimen or a structure. The pullout test is a test that falls in the transition area between a destructive test and a non-destructive test. It is destructive in the sense that a relatively large volume of the concrete is damaged but non-destructive because the damaged can be repaired. By the use of correlation curves the pullout test can be used to make reliable estimates of in-place strength. Schematic representation of pull out test is shown in Figure 9.

Pulloff test

This test involves attaching a plate to the concrete using epoxy resin and, after curing has taken place, measuring the force required to pull the plate off. This test scars the concrete but gives a measure of the near surface tensile strength which can be converted to the compressive strength provided a correlation exists between the compressive strength and tensile strength for the concrete mix being investigated.

Core test

In most structural investigations or diagnoses extraction of core samples is unavoidable and often essential. Cores are usually extracted by drilling using a diamond tipped core cutter cooled with water.

Conclusion

NDT methods have materialized as a response to the need for structural damage detection and prevention. The extensive use of NDT is driven by economics and safety. In a pre-emptive attempt to eradicate the problems associated with structural deterioration, novel in-site testing techniques have been invented to allow for the assessment of concrete during the construction, commissioning and servicing lifecycle stages of a structure. The major factors that influence the success of a non-destructive survey are depth of penetration, vertical and lateral resolution, contrast in physical properties, signal-to-noise ratio and existing information about the structure. The understanding of material properties and the key issues associated with their application in structural engineering is imperative for the success of any NDT method.

Reference

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