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Non-destructive Test Methods for RCC OHWT: A Review

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Abstract: Keeping in view the visual observations, a comprehensive test programmed was planned for condition assessment. NDT can be applied on old as well as new concrete. In case of new concrete, the application is done for quality control. The testing of existing structure is usually related to an assessment of structure integrity. It takes less time for testing and large number of tests performed on a structural element in compare to destructive testing. This study reviews the common non-destructive testing (NDT) methods of concrete components that are used by structural engineers. In non-destructive testing, some factors that influence the results of the non-destructive test (NDT) are discussed and recommend a way to overcome their influence. Standard guidelines are referred for interpretation of NDT methods. The potential, interpretations, inspection techniques, and limitations of NDT methods are explored. For evaluating the strength, durability, uniformity, and other properties of concrete structures, NDT is an acceptable method. The purpose of this study is to tackle all these problems by identifying and narrating the methods of NDT as applied to the RCC OHWT.

Keywords: Non-destructive testing, Visual observations, Structure integrity, Durability, Retrofitting, overhead water tank, Condition assessment.

I. INTRODUCTION

The attention towards the old RCC structure and the urgency of their repair and rehabilitation are relatively recent. The repair and rehabilitation of structure clearly shows the limit of knowledge in the field of evaluation to gather the data necessary to the analyses. The current need, which will develop in future, is directed towards the non-destructive testing and instrumentation of structure to compute in-situ properties of construction materials. The assessment of quality of concrete is of cardinal importance in order to ensure whether the quality of execution is satisfactory or not. Any deficiencies observed can be rectified. Besides visual inspection this can be achieved only by conducting some In-situ testes on the structures.

Accurate assessment of physical, chemical and electro-chemical properties is of significant importance in order to enhance the existing life of the structure. There are two kinds of in-situ tests viz. non- destructive or partially destructive tests. Assessment of the structure is made properly if the cause of deterioration is known. This can result into economically feasible repair of the distressed structure and consequently prolong life.

Numerous Non-Destructive Tests (NDT) and Partially Destructive Tests (PDT) need to be carried out to evaluate the extent of distress and to estimate the quality of concrete, before repair. Although the NDT and PDT methods indirectly estimate the compressive strength of concrete. With the advent of Non-Destructive testing techniques in civil engineering during 1940, primary need of the engineers was the in-situ determination of the homogeneity and the compressive strength. The majority of these techniques are based on the measurement of the surface hardness of the concrete.

SCHMIDT REBOUND HAMMER TEST:

Schmidt Rebound Hammer for measuring the hardness of concrete, developed by a Swiss engineer, Ernest Schmidt in 1948. Modern versions of the hammer based on it. The spring-controlled hammer mass slides on a plunger within a tubular housing. The spring is tensioned when pressed against the concrete surface and automatically release when fully tensioned, plunger impact the concrete by hammer mass. When the spring-controlled mass rebounds, the extent of such rebound is proportional to the surface hardness of concrete. And takes rider with it which slides along a scale and visible through a window in the side of casing. It's operated either horizontally or vertically, either upwards or downwards. The plunger is pressed steadily and strongly against the concrete surface at right angles. Test reading recorded from the scale is known as Rebound Number, and is an arbitrary measure since it depends on the energy stored in the spring and on the mass used. There is different code used in different century but in India IS-13311 part-2 (1992) is used for testing.

Table1.1 Impact Energy for Rebound Hammer for Different Applications

Sr No.	I	ii	iii
Application	For testing normal weight concrete	For testing light-weight concrete	For testing mass concrete (roads, airfield pavement and hydraulic structure)
Approximate Impact Energy Required for the Rebound Hammer (Nm)	2.25	0.75	30.00

Figure 1-1 Schmidt Rebound Hammer Test

For testing, surface should be smooth, clean and dry. Rough surfaces result of improper compaction or loss of grout. If any loos material present remove with the help of grinding wheel. The surface impact point should be 20mm away from the edge and impact point should not less than 20mm from each other. At the time of testing rebound hammer should be held at right angle. If in any situation rebound hammer tilted the rebound number is different for same concrete, correction factor may be applied. In latest digital automatic rebound hammer, all correction applied automatically. Eight reading takes at every location, minimum and maximum reading not consider in the calculation.

Table 1.2 Quality of Concrete Cover

INSTRUMENT	Schmidt Rebound Hammer N-Type				
AVERAGE REBOUND NUMBER	Greater than 40	30 to 40	20 to 30	Less than 20	0
QUALITY OF CONCRETE	Very good hard layer	Good layer	Fair	Poor concrete	Delaminated

ULTRASONIC PULSE VELOCITY TEST:

Another way to assess the condition of concrete is using Ultrasonic Pulse Velocity (UPV) test method. Generally, a concrete member will be divided into well-defined grid points of spacing of 250 -300mm and pulse velocities can be determined using standard instruments. A systematic scanning can give useful information about concrete condition and also this method helps to identify locations, which are corrosion-prone. This method of testing may be used to determine;

- The homogeneity of concrete
- Presence of voids, cracks or other imperfections
- Changes in concrete quality due to internal and external agencies
- Quality of concrete to the specified requirements required for the interpretation of results.

From the pulse velocity measurements, the quality of concrete is rated as in Table.1.3 and combining UPV and Rebound Hammer readings can identify locations prone to corrosion damage. Code used for the UPV testing: IS 13311 part-1 (1992).

Table 1.3 Quality of concrete

Sr. No.	UPV value (m/sec)	Concrete Quality Grading
1	Above 4500	Excellent
2	3500 – 4500	Good
3	3000 – 3500	Medium
4	Below 3000	Doubtful

There are three possible methods of testing according to the type of surface:

a) Opposite faces (direct transmission)
b) Adjacent faces (semi-direct transmission)
c) Same face (indirect transmission)

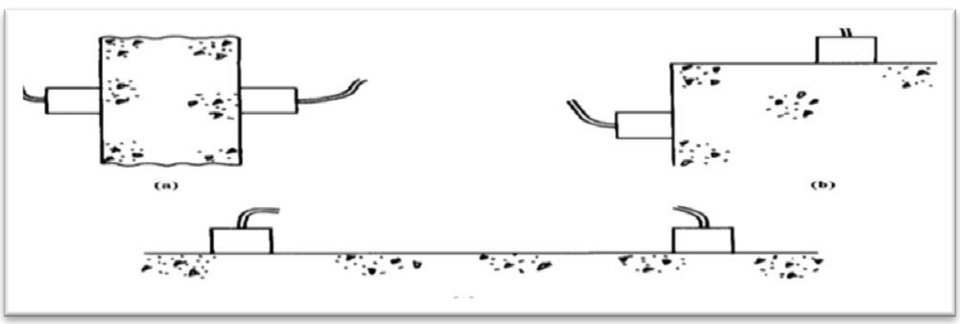

Figure 1-2 Type of reading: (a) Direct; (b) Semi-direct; (c) Indirect

Figure 1-3 Ultrasonic Pulse Velocity Test

CHEMICAL TEST ON CONCRETE:

(i) Carbonation Test:

Concrete chemistry is tough to understand for the normal people. Spends some money for the concrete carbonation test is an excellent idea to known the effect of the atmospheric carbon dioxide on the RCC structure. Cement paste is naturally alkaline in nature, which forms a protective oxide coating on steel reinforcement that prevents the steel from rusting. When carbon dioxide (CO_2) in the air penetrates into concrete, it reacts with the calcium hydroxide ($CaOH_2$) in the cement paste producing calcium carbonate ($CaCO_3$). This reaction is called carbonation. The alkalinity of the cement paste tends to decrease due to the carbonation. The pH value decreases below 13. The protective oxide coating is destroyed when the pH drops below 9 and the steel were corroded in the presence oxygen and of moisture. For reinforced concrete structure the evaluation of corrosion is done by measurement of the depth of carbonation.

Indicator is sprayed on a newly cut core or freshly broken piece of concrete and allowed to dry, for measure the pH of the cement paste, colours indicate the approximate pH of the paste as illustrated below.

Figure 1-4 Carbonation

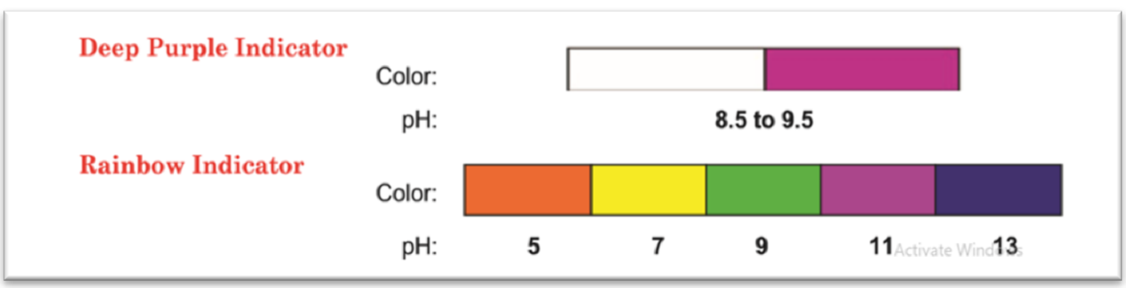

Figure 1-5 Color Indicator

For determination of depth of carbonation in samples of field concrete Rainbow and Deep Purple Indicator are used.

Carbonation depth can be used for the following purposes:

- To evaluate the cause of corrosion when conducting corrosion surveys
- To estimate service life where penetration of the carbonation front is critical
- To monitor the effectiveness of procedures for re-alkalization of the cover layer
- To make a rough estimate of concrete strength from the age of concrete and the relative humidity

(ii) Chloride Content Test on Concrete:

Core samples or broken samples of concrete are used to determine the chloride content. It is important to know the level of chloride near the steel-concrete interface. Free (water soluble) as well as fixed (water insoluble) chloride present in concrete.

The total acid soluble chloride is determined in accordance with IS: 14959 Part – II – 2001, Maximum Total Acid Soluble Chloride Content Maximum Total Acid Soluble Chloride Content Expressed as kg/m3 of concrete 0.6 kg/m3 of concrete.

whereas for assessment of water-soluble chlorides the test consists of obtaining the water extracts, and conducting standard titration experiment for determining the water-soluble chloride content and is expressed by water soluble chloride expressed by weight of concrete or cement.

The method gives the average chloride content in the cover region. Further a chloride profile across the cover thickness will be a more useful measurements as this can help to make a rough estimate on chloride content diffusion rate.

One recent development in the field-testing of chloride content includes the use of chloride ion sensitive electrode. This is commercially known as "Rapid Chloride test kit-4".

The test consists of obtaining powdered samples by drilling and collecting them from different depths (every 5mm), mixing the sample (of about 15.g weight) with a special chloride extraction liquid, and measuring the electrical potential of the liquid by chloride-ion selective electrodes.

With the help of a calibration graph relating electrical potential and chloride content, the chloride content of the samples can be directly determined.

(iii) Sulphate test on concrete

Sulphates are present in most cements and in some aggregates; Exposure of concrete made with Portland cement to sulphate salts can cause damage due to an expansive reaction between the cement and the sulphate salt to form crystals of ettringite. Given adequate space to form, the ettringite forms needle like crystals, causes an expansive reaction. Test performed as per IS-2317 (1975) (RA 2015).

Preparation of sample:

Sample is broken into smaller pieces by hammering carefully to avoid loss of smaller pieces. Particles are crushed to less than 25 mm in maximum dimensions; care is taken to restrict negligible levels of loss of fine particles. Crushed sample is sieved through 850 microns IS Sieve. Thoroughly blend the material by transferring it from one glazed paper to another at least 10 times. Sulphate content should not exceed 4 precent by mass of the cement in the mix.

CONCRETE RESISTIVITY TEST:

The corrosion of steel in concrete is an electrochemical process that generates a flow of current. Resistivity of the concrete influences the flow of this current. The lower the electric resistance, the more easily corrosion current flow through the concrete and the greater is the probability of corrosion. Thus, the resistivity of concrete is a good indication of probability of corrosion. Resistivity Meter can measure the electrical resistance of reinforced concrete components.

The probable rate of corrosion with respect to value of resistivity of concrete is normally considered as given in table below.

Table 1.4 Estimation of the likelihood of corrosion

Resistively level (Kilo-ohm/cm)	Possible corrosion rate
≥ 100 kΩ/cm	Negligible risk of corrosion
50 to 100 kΩ/cm	Low risk of corrosion
10 to 50 kΩ/cm	Moderate risk of corrosion
≤ 10 kΩ/cm	High risk of corrosion

Figure 1-6 Concrete Resistivity

PARTIALLY DESTRUCTIVE TESTING:

CORE TEST:

The examination and compression testing of cores cut from hardened concrete is a well-established method, enabling visual inspection of the interior regions of a member to be coupled with strength estimation. Other physical properties, which can be measured, include density, water absorption, indirect tensile strength and movement characteristics including expansion due to alkali–aggregate reactions. Cores are also frequently used as samples for chemical analysis following strength testing. In most countries standards are available which recommend procedures for cutting, testing and interpretation of results; IS-516 part-4 in India, BS EN 12504-1(135) in the UK, whilst ASTM C42 (136) and ACI 318 (137) are used in the USA. A core drill shall be used for cutting cylindrical core specimen. A core specimen for determination of pavement thickness shall have a diameter of at least 10 cm. A core specimen for the determination of compressive strength shall have diameter at least 3 times of the maximum nominal size of aggregate use in concrete. Length of the specimen is nearly twice of its diameter.

Figure 1-7 Core Test

1.4.3 (b) CUT AND PULLOUT TEST (CAPO):

In CAPO test measuring the force required to pull out an embedded metal insert and the attached concrete fragment from a concrete test specimen or a structure assesses method pull-out strength of hardened concrete. The insert is either cast into fresh concrete or installed in hardened concrete. The basic idea behind pull-out testing is that the test equipment designed to a specific geometry will produce results (pull-out forces) that closely correlate to the compressive strength of concrete.

Procedure:

While selecting locations for capo test, first make sure that no reinforcing bars should be in the failure zone. This can be made sure by using Ferro scanner, when this instrument detects reinforcement bars it gives sound alerts. Using this method, we can choose a suitable location for the capo test. Then a perpendicular hole or a core of diameter 18.40mm is drilled using diamond studded core bit of length 68-69mm. Then cantering and governing rod is inserted in the hole and diamond-planning tool is employed to ground the surface to depth of 3-5mm. Then a recess is routed in hole to diameter of 25mm at depth of

25mm.then a metal split ring is inserted and expanded in recess by two manually held opposite rotating wrenches. And then the whole assembly including ring and the concrete cone embedded are pulled out using pull-out machine, while reacting against 55mm diameter counter pressure ring. With this concrete is behaving like a strut between counter pressure ring and expanded ring. hence the ultimate pull-out force is directly related to concrete strength. The test is performed till the conc frustum is totally detached from the element. Now there is minor damage in structure, which can be repaired easily without affecting its serviceability and functional capacities.

Figure 1-8 Cut and Pullout Test (Capo)

II. RESEARCH AND STUDIES ON NON-DESTRUCTIVE TESTING

Relevant research work and studies are reviewed here:

Bhaskar S. et al. (2006) (1) This paper discussed a case study, the assessment of 30 years old overhead Reinforced Cement Concrete (RCC) reservoir by NDT and PDT methods. The main aim of the paper was to highlight the importance and significance of different test methods employed to assess the present condition of RCC structure. A rational and systematic approach for the interpretation of test results based on NDT and PDT is presented for arriving at an economical repair procedure and rehabilitation measures. Necessary repair measures are suggested to enhance the service life of the structure.

A detailed systematic methodology in conducting the condition assessment of overhead RCC reservoir was presented. This includes visual observation and documentation, ultrasonic testing on columns and brace beams for assessing the integrity of concrete, core sampling and testing for estimating the compressive strength and water absorption. Half-cell potential measurements were also carried out for assessing the presence of corrosion activity. The test results have been interpreted, and finally assessed the overall concrete quality and integrity. Based on the test results, it was found that the distressing of the supporting structure was mainly due to voids, honeycombing and carbonation of concrete. Necessary repair measures are suggested to improve the strength and performance of the structure in a qualitative manner.

Aydin and saribiyik et al. (2010) (2) In the study, authors have determined a correlation between NDT and concrete compressive strength test. The author has used cubes of 28-90 days age and samples from different RCC structures for testing. The best-fit correction factor for the relationship has been found through processing the correlation among various data sets according to author rebound hammer on old structure give high variations which make engineering judgement quite difficult. Rebound Hammer results are influenced by many factors such as carbonation, moisture and curing type. the author has concluded as Rebound hammer results can be used to reduce no. of core samples to be taken from the test site.

D. Rama Seshu et al. (2013) (3) In this study authors evaluated the strength of existing bridge pier. Correlating the NDT observations with core tests made the assessment of quality and strength. The assessment involves the core tests, Rebound hammer tests and Ultrasonic pulse velocity tests. In a T-beam girder bridge, constructed across a river in India, it was reported that the strength of concrete in one of the piers could not be achieved in the testing of corresponding concrete cubes. Further, the core samples collected gave different strength values. In this connection, it was recommended to have the grouting of the pier. After the grouting carried out in accordance with the required procedure the Non-destructive test was carried-out using Rebound hammer and Ultrasonic pulse velocity tester. Further to quantify the strength of concrete three core samples were also collected for testing.

The testing was conducted in the presence of concerned Engineering personal. The diameter and height of the pier are 1.8m and 3.35 m measured from base to the bottom of the pier cap, respectively. The various NDT techniques are very useful in estimating the quality and strength of existing concrete structures. The case study presented here illustrates the correlation between destructive and NDT results in the comprehensive assessment of structural condition.

Wankhade Rajan L. et al. 2013 (4) In this study authors developed systematic investigation for metrology and a condition ranking procedure based on Analytical hierarchy process (AHP) has been proposed. DER rating technique was used to find out the condition ranking of elevated service reservoir in Karad region in Maharashtra (India). The ranking assessment for elevated service reservoir structure has been carried out using different Non-destructive test methods like half-cell potential methods, cover depth measure, surface hardness and ultrasonic pulse velocity test. The condition index (CI) for RCC ESR at GCE, Karad was found to be CI =16.48 which implies that condition of the water tank was very poor there and extensive deterioration has occurred and the water tank was barely functional. For water tank at Malkapur in Karad region, CI=40.05, it means that condition of the water tank was fair, moderate deterioration occurred and function is still adequate. Thus, using DER rating technique Condition Ranking of RCC ESR's are found out.

G. B. Ramesh Kumar et al. (2014) (5) has briefly discussed various NDT techniques such as Rebound Hammer, Ultrasonic Pulse Velocity, Carbonation Test, Rebar Locator Test & Impact Echo Test, from a practical standpoint of an experienced Structural Engineer along with some partial-destructive testing methods of in-situ concrete. It is important to note that almost all the NDT methods indirectly estimate the concrete strength and strength obtained by these methods, in most of the cases, is comparable. Even then, no single method can be said to be fully reliable and therefore, more than one method should be performed and results should be correlated.

Helal J. et al. (2015) (6) In this paper authors reviews the most common non-destructive testing (NDT) methods of concrete structures as utilized by the structural engineering industry. The fundamentals of NDT methods are explored in regards to their potential, limitations, inspection techniques and interpretations. Perceptions of NDT inadequacy were attributable to a lack of understanding of construction materials and NDT methods themselves. This paper intends to address these concerns by identifying and describing the most common successful methods of NDT as applied to concrete structures. A wide range of non-destructive testing methods has been reviewed concerning their potential, limitations, inspection techniques and interpretations. The factors that influence the success of NDT methods were explored and ways to mediate their influence were recommended. It was found that the majority of NDT methods rely on comparing tested parameters with established correlations. Empirical relationships provided by manufacturers were found too often provide unsatisfactory results. Where applicable, it is recommended to conduct test specific correlation procedures for the NDT of concrete.

Moczko, Carino, Petersen (2016) (7) Authors addressed the problem that whether carbonation has an effect on capo reading or not. For this author used data from fifteen bridges with age ranging from 25-52 years. for every bridge core strength, average values and capo pull out strength be obtained. 2-35 mm carbonation depth were measured using chemical staining methods. The author first anticipated that due to carbonation in cover layer, capo reading will be increased, but after investigation author confirmed that very negligible or no effect has been observed. Also, it was found that capo results were 2.8 per cent greater than measured core strengths.

TURGUT P. et al. (2020) (9) had come up with a formula to find the approximate compressive strength of concrete from the UPV values of the specimen.
The formula as follows:

$$S_n=0.316\, e^{1.03V_n}$$

He has also found that high strength concretes are evaluated very accurately on basis of UPV values, the author also said that concrete having high strength the UPV value increase relatively, the author has determined the relationship between UPV and concrete strength by using data obtained from cores of different concrete structures of different ages and have unknown mixes. The author has used some earlier researches for this relationship, the author has not considered mix ratios. According to the author, the mix ratio can be ignored by using a given formula. for this study author took samples from 30 RCC structures aged from 28 days to 36 years old, and 86 cores have been obtained densities vary from 1.88 to 2.60 kg/cm3. Cores we obtain from columns, shear and retaining walls. size of cores was 100*200mm.

III. CONCLUSIONS

After going through the various research carried out by many researchers, it may be concluded that:

1. It was observed that not enough research work has been done on the condition assessment of OHWT with the help of NDT.
2. There is very less study has been done as condition assessment based on the age group of the structure.
3. From the above literature, it is seen that Study on CAPO (Cut and pull out) test is very less on these types of an old structure.
4. The previous study of NDT on the old structure has covered some particular type of test. There is very less study has been done which covered all the tests and make a significant correlation between them.
5. After above conclusion there is a need of separate study on different types NDT test for the condition assessment of old concrete structure.

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