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Assessment of Structural Integrity Using NDT

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***Abstract*- It is often necessary to investigate the concrete structures after the concrete has hardened to determine whether the structure is suitable for its intended 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, 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.

***Keywords*— ESR/Elevated Service Reservoir, Rebound Hammer, Ultra Sonic Pulse Velocity, Core Tester, Photometer.**

I. INTRODUCTION

In any manufacturing, fabrication or production process, the quality of the structure or component produced is a key factor in the long term economic and engineering success of that process. Increasing awareness of the importance of quality in every area of technology has resulted from sensitivity to the growing pressure of international competition, more discriminating demands from the marketplace and stricter consumer protection and product liability legislation. The human factor is of great importance in the quality control construction.

Concrete is a strong handy building material that has found favor amongst the Civil Engineers due to ease of production and capability of being molded into any shape and size.

Its quality, performance and behavior depend upon its constituents and the method of production. In the earlier times the period when most of the old RCC structures were built, the emphasis was primarily on the 28 days strength of the concrete. Little was known about the long-term behavior of concrete i.e., durability, as the earlier versions of IS 456:1978 was silent on this aspect. Though environmental factors or exposure conditions were known to cause damage to concrete, but many of the places are free from pollution and far away from the sea, the environmental factors were not considered for these types of structures.

Non-destructive testing (NDT) finds prominence in quality assurance of construction industry. It has great potential in investigation and repairs to various types of structures. Simple NDT techniques can be used to identify weak areas in concrete, which can be suitably repaired. Non-destructive testing is defined as testing that causes no structurally significant damage to concrete. It does not impair the intended performance of the element or member under investigation. NDT has the ability to determine the strength and durability of critical construction without damaging them and test can be carried out on site.

NDT is becoming popular now a day as no damage occurs in structures while testing. It gives rapid assessment of existing condition of structure it is used for wide range of objectives as discussed before. NDT includes testing right from visual inspection to the advanced techniques available for the testing of structures. NDT is applied not only in quality control and routine inspection but also in diagnostic investigations.

II. METHODS ADOPTED FOR NDT

(a) Rebound Hammer Test

The Schmidt Rebound Hammer measures the hardness of material at the surface. The mass is released from a standard pre-compressed spring thus having a fixed amount of energy. Principle of this test is that the rebound of the elastic mass depends on the hardness of the surface upon which it impinges. Energy is lost on impact due to localized crushing and internal friction within the body of the concrete. This internal friction is the function of the elastic properties of concrete constituents.

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Rebound Number is the distance traveled by the mass after the elastic impact expressed as a percentage of original distance. This gives a measure or indication of hardness and an estimate of the strength of concrete. There are several factors other than concrete strength that influence rebound hammer test results, including surface smoothness and finish, moisture content, coarse aggregate type, and the presence of carbonation.

Although rebound hammers can be used to estimate concrete strength, the rebound numbers must be correlated with the compressive strength of molded specimens or cores taken from the structure.

However, within certain constraints, the empirical correlation provided by one of the researcher Facaoaru (MINT, 2006), is:

$$\mathbf{K = a\ Nb} \qquad \text{(a)}$$

where N: rebound index; K: compressive strength; a and b are constants depending on moisture content of concrete and dosage of cement, age of concrete, and in special cases, the type of cement.

The estimated error in this method is +30%. Again, the calibration equation (2.1) is valid for a particular type of cement, aggregates used, moisture content, & age of specimen. (Deshpande, 2004).

(b) Ultra-Sonic Pulse Velocity Test

The velocity of ultrasonic pulses traveling in a solid material depends on the density and elastic properties of that material. Ultrasonic testing is used to detect internal flaws which send echoes back in the direction of the incident beam and these are picked up by a receiving transducer. The measurement of the time taken for the pulse to travel from a surface to a flaw and back again enables the position of the flaw to be located. Such a technique is mainly used in metals because if this is applied to heterogeneous materials like concrete and timber, echoes are generated at numerous boundaries of different phases resulting in scattering of pulse energy in all directions.

The frequencies generally used lies in the range of 20 kHz to 250 kHz with 50 kHz being most suitable for concrete. The wavelength corresponding to this frequency range is about 200 mm to 16 mm.

For assessing the quality of material from ultrasonic pulse velocity measurement, it is necessary for this measurement to be of higher order of accuracy i.e (+/-) 1%.

Pulse Velocity = Path Length / Transit Time

The instrument used for this test is known as PUNDIT, Portable Ultrasonic Non Destructing Digital Indicating Tester. It indicates the time taken for the earliest part of the pulse to reach the receiving transducer. There are three methods of testing depending on the arrangement of the transducers namely;

Direct: where Transmitting and Receiving Transducers are on the parallel surfaces.

Indirect: where Transmitting and Receiving Transducer are on the same surface.

Semi Direct: where Transmitting and Receiving Transducers are on the perpendicular surfaces.

Pulses are not transmitted through large air voids in a material or it takes a longer time to travel through such voids. So it is possible to detect voids through this test. (Deshpande, 2004) (PUNDIT User Manual).

III. Problem Statement

A. Alarakha Ka Par, Ramsar, Barmer

The ESR at Alarakha Ka Par, Ramsar, Barmer started about July 2015. The ESR designed, vetted and approved at competent level for staging of 20 m and capacity of 300 KL. Stairs were not constructed up to first bracing. According to Tender stipulation it was proposed at first bracing. It was reported that the construction of ESR up to first bracing was taken up in Nov 2015. The height of first bracing is 3.75 m. It was completed in three lifts. The laboratory cube test of second lift of first bracing column (between 1.2 m to 2.5 m) results were failed marginally at 28 days strength, Copy of mix design and record of site testing both destructive and Non Destructive were made available. The visiting team interacted with the persons present at the site and could find that the work was stopped due to noncompliance of specification in the tender document. NDT tests were conducted at the site by contractor representatives. Some of data which could be gathered are: 8 columns in plan, Size of brace beam 450 mm by 500 mm, Height of first brace (from its bottom) 3.75 m, Dia of Column 450 mm. The site is in close vicinity of Pakistan Border about 8-10 km. The watch towers of the Border Security Force were visible.

Quality of Concrete of the Structure: - The mix design report conducted in 2015 and approved. In the mix design report value of parameter K is taken as 1.65, stating that not more than 5 % of results are expected to fall below f_{ck}. The proportion recommended is 0.44:1.00:1.62:2.90. The report clearly mentions that no admixture has to be used. No representative of either the department or the contractor was present during the process.

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Site Testing aspect: - It was submitted by the client the data regarding test carried out at the site i.e. photocopy of the register where other tests are also mentioned. It clearly shows that the date of testing was 04-11-2015, grade of concrete M30, quantity of Concrete 1.6 m^3. Further testing data mentions data of tests as 28.67, 28.67 & 27.33 N/sq mm making an average of 28.22 N/sq mm. The NDT tests were carried out by the CEG test house of Jaipur dated 13-12-2016. UPV test results show a value of 4.57 km/sec keeping ambient temperature as 27.2 ^oC by direct method for Alla rakha ka par II lift FB-I to TB-I at column-1 and date of testing as 10-12-2016. Rebound Hammer test results show a value of 47 MPa with rebound hammer no as 43 in horizontal position & dry condition. The tests were carried out as per IS 13311 part I & II: 1992.

B. Banwa, Ramsar, Barmer

The ESR at Banwa, Ramsar, Barmer started about Aug 2015. The ESR designed, vetted and approved at competent level for staging of 20 m and capacity of 200 KL. Stairs were not constructed up to first bracing. According to Tender stipulation it was proposed at first bracing. It was reported that the construction of ESR up to first bracing was taken up in Dec 2015. The height of first bracing is 3.75 m. It was completed in three lifts. The laboratory cube test of second lift of first bracing column (between 1.2 m to 2.5 m) results were failed marginally at 28 days strength, Copy of mix design and record of site testing both destructive and Non Destructive were made available. The visiting team interacted with the persons present at the site and could find that the work was stopped due to noncompliance of specification in the tender document. NDT tests were conducted at the site by contractor representatives. Some of data which could be gathered are: 8 columns in plan, Size of brace beam 450 mm by 500 mm, Height of first brace (from its bottom) 3.75 m, Dia of Column 450 mm.

Quality of Concrete of the Structure: - The mix design report conducted in 2015 and approved. In the mix design report value of parameter K is taken as 1.65, stating that not more than 5 % of results are expected to fall below f_{ck}. The proportion recommended is 0.44:1.00:1.62:2.90. The report clearly mentions that no admixture has to be used. No representative of either the department or the contractor was present during the process.

Site Testing aspect: - It was submitted by the client the data regarding test carried out at the site i.e. photocopy of the register where other tests are also mentioned. It clearly shows that the date of testing was 04-12-2015, grade of concrete M30, quantity of Concrete 1.6 m^3. Further testing data mentions data of tests as 28.98, 28.12 & 27.66 N/sq mm making an average of 28.25 N/sq mm. The NDT tests were carried out by the CEG test house of Jaipur dated 13-01-2017. UPV test results show a value of 4.27 km/sec keeping ambient temperature as 27.2 ^oC by direct method for Banwa III lift FB-I to TB-I at column-1 and date of testing as 10-01-2017. Rebound Hammer test results show a value of 47 MPa with rebound hammer no as 43 in horizontal position & dry condition. The tests were carried out as per IS 13311 part I & II: 1992.

IV. Objective Of Nondestructive Investigation

To assess the existing quality, integrity and allowable compressive strength of concrete in the raft, beam, column and foundation and super structure element which can be utilized for overall structural safety. Besides, in case of any inadequacy in the concrete quality being revealed, suitable remedial measures can also be suggested.

V. NDT Results

Non Destructive Test results are given below on the randomly selected elements accessed easily on the structure.

TABLE I
Results of Rebound Hammer Test at Alla rakha Ka Par ESR

Member	Minimum Rebound No.	Maximum Rebound No.	Standard Deviation	Average Rebound No.	Related fck
Columns 1-8 Lift II All readings in horizontal position					
Columns 1	36	42	2.5	40.2	42.8
Columns 1	41	46	2.7	43	48.1
Columns 2	30	36	2.5	33.6	31.1
Columns 3	35	41	2.5	37	37
Columns 4	30	43	4.8	35.6	34.5
Columns 4	34	40	2.3	36.6	36.3
Columns 1-8 Lift III All readings in horizontal position					
Columns 1	36	40	1.6	38.8	40.3
Columns 2	30	38	3.5	34	31.8
Columns 3	34	46	5.1	40	42.5
Columns 3	36	39	1.5	37.4	37.7
Columns 4	37	30	5.5	40.6	43.6
Columns 4	38	44	2.6	41.2	44.7
Columns 5	33	49	6.1	38.6	39.9
Columns 5	35	37	0.9	36.4	35.9
Columns 6	36	45	3.8	40.8	44
Columns 7	33	49	5.7	40.6	43.6
Columns 7	32	46	5.0	38.4	39.55
Columns 7	40	46	2.4	42.2	46.6
Columns 7	36	44	3.0	39.4	41.4
Columns 8	39	46	2.8	41.8	45.8

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TABLE-II
RESULTS OF ULTRASOUND PULSE VELOCITY TEST AT ALLA RAKHA KA PAR ESR

Member Lift II	Length mm	Time µ sec	Velocity m/sec	Value of R considered from RH/ σ N/mm 2
Column 1/D	450	104.8	4290	43
Column 4/D	250	117.7	2120	35
Column 4/ID	300	169.5	1770	35
Column 4/ID	450	105.7	4260	35
Column 5/D	450	106.5	4230	34/28.1
Column 1/D	450	104.8	4290	43/26.8
Member Lift II				
Column 7/D	450	103.7	4340	43/35.9
Column 7/ID	450	231.0	1950	43

TABLE III
RESULTS OF REBOUND HAMMER TEST AT BANWA ESR

Member	Minimum Rebound No.	Maximum Rebound No.	Standard Deviation	Average Rebound No.	Related fck
Columns 1	24	39	5.6	33	30.1
Columns 1	39	53	6.7	43.8	49.7
Columns 1	28	52	11.1	37.2	37.4
Columns 1	36	40	1.8	37.6	38.1
Columns 1	34	38	1.5	36.2	35.6
Columns 2	27	46	7.1	38	38.8
Columns 2	38	39	0.4	38.8	40.3
Columns 3	31	40	3.4	36.6	36.3
Columns 4	34	41	2.9	37	37
Columns 5	24	39	5.7	31.4	27.4
Columns 5	36	39	1.1	37.8	38.4
Columns 6	25	49	10.9	36.4	35.9
Columns 6	28	47	7.3	34.8	33.1
Columns 6	33	46	3.6	40	42.5
Columns 6	35	41	2.3	38.6	39.9

TABLE-IV
RESULTS OF ULTRASOUND PULSE VELOCITY TEST AT BANWA ESR

Member Lift II	Length mm	Time µ sec	Velocity m/sec	Value of R considered from RH/ σ N/mm 2
Column 1/D	450	111.7	4040	37
Column 1/D	450	245.0	1840	37
Column 3/ID	450	113.6	3890	36
Column 3/ID	450	249	1810	36
Column 6/D	450	110.9	4060	37
Column 6/D	450	242	1860	37

VI. SOME CITATIONS

With reference to IS 456-2000, Clause 16 Acceptance Criteria and Clause 16.1 for Compressive Strength, The Concrete shall be deemed to comply with the strength requirements when both the following conditions are met:-

The mean strength determined from any group of four consecutive test results complies with the appropriate limits in column 2 of table 11

Any individual test results complies with the appropriate limits in column 3 of table 11

Clause 16.3 Quantity of Concrete Represented by Strength Test Results

Clause 16.3 states ie the quantity represented by a group of four consecutive test results shall include the batches from which the first and last were taken together with all intervening results.

Clause 16.6 Concrete is liable to be rejected if it porous or honey combed, its placing has been interrupted without providing a proper construction joint, the reinforcement has been displaced beyond the tolerances specified, or construction tolerances have been met, However, the hardened concrete may be accepted after carrying out suitable remedial measures to the satisfaction of the Engineers In charge.

Clause 17.3 Testing Clause 17.4.3, Concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of cores is equal to at least 85 percent of the cube strength of the grade of concrete specified for the corresponding age and no individual core has strength less than 75 percent.

VII. THE PURPOSE OF THE INSPECTION

The purpose of the inspection is to provide advice to a prospective or other interested party regarding the condition of the structure at the time of the inspection. The advice is limited to the reporting of the condition of the structure in accord with IS 456. This report is limited to (unless otherwise noted) the main structure on the site. This report is not intended as a certificate of compliance of the structure within the requirements of any act, regulation, and ordinance or by law, or, as a warranty or an insurance policy against problems developing with the building in the future.

Assumptions & Limitations-

- Any person who relies upon the contents of this report does so acknowledging that the following clauses, which define the Scope and Limitations of the inspection, form an integral part of the report.

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- This NDT inspection is limited to those areas and sections of the structure fully accessible and visible to the Inspector at the time and on the date of Inspection.
- The inspection DID NOT include breaking apart, dismantling, removing or moving objects including, but not limited to, foliage, moldings, sparking membrane, appliances or personal possessions.
- Provisions of IS 13311 part I and part II 1992 applies in addition to provisions of IS 516 latest version applies. So far as mix design is concerns provisions of IS 10262 and SP 23 latest versions shall comply. Needless to say that Provisions of IS 456-2000 also applies.
- The visiting team DID NOT dig, gouge, force or perform any invasive procedures.
- Nothing contained in the Report implies that any inaccessible or partly inaccessible area(s) or section(s) of the structure being inspected by the Inspector on the date of the inspection were free from defects latent or otherwise.
- No responsibility can be accepted for defects which are latent or otherwise not reasonably detected on limited requirement.
- Durability of exposed finishes.
- Photographic evidence taken on the day of inspection is given as an example of the NDTs found to the structure for reporting purposes only. These photos within the report are to assist, and May not show all the tests and/or the areas noted on the day of inspection.
- Any person who relies upon the contents of this Report does so acknowledging that the above clauses, definitions and disclaimers that follow define the Scope and Limitations of the inspection and form an integral part of the report.
- Disclaimer of Liability: No liability shall be accepted on account of failure of the Report to notify any problems in any area(s) or section(s) of the subject structure physically inaccessible for testing purpose, or to which access for testing is denied by or to the visiting team (including but not limited to any area(s) or section(s) so specified by the Report.
- Disclaimer of Liability to Third Parties: This report is made solely for the use and benefit of the Client named on the front of this report. No liability or responsibility whatsoever, in contract or tort, is accepted to any third party who may rely on the Report wholly or in part. Any third party acting or relying on this Report, in whole or in part does so at their own risk.
- As requested in letter referred above of the party, care has been taken not dig out a core however combined method of Rebound hammer and Ultra Sonic Pulse Velocity meter were applied.

VIII. Suggestion

It is suggested that the construction should not be discontinued for so long time as it can hamper quality of construction. Other agencies can further deteriorate quality of materials used and part of the construction which has made the progress.

IX. Recommendations

All process should be including testing, witnessed by either the contractor or the agency owning the construction. The matter may be referred to a competent authority as per norms of NDMA considering Qualification and experience of the expert concerned. Ultimately onus lies on the agency owning the construction later on.

X. Conclusion

According to this investigation we can clearly see that for Non Destructive Evaluation of Defects in Concrete Rebound Hammer test is not the one that can be relied upon. Though from data obtained (R number) we can clearly see that it gives some indication of the presence of some defect but strong conclusion can't be drawn from these results. Also if the concrete specimen is such that it's R value is low (that is R<18) than by Schmidt Hammer we can't get the R value at all (at any point) and the little bit indication that we were able to draw from this test about the presence of discontinuities could not be drawn and in that case this test will be a complete failure. So the only conclusion that can be drawn here is that Rebound Hammer test is of negligible importance in detecting defects in concrete. From this investigation it can be seen that the USPV Test is the one on which we can completely rely to serve our purpose.

Unnecessary obstacles should be avoided. Looking to provisions of table 11 of IS 456-200 the case reported falls under individual category i.e. fck - 4 N/sq mm should be criteria for acceptance. So far as the citation quoted and visit at the site including other parameters, reported and generated, it is felt that there should not be an issue so far quality of Concrete is concerned. However the final verdict rests with the site in charge Engineer to decide.

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