Non Destructive Investigation of ESR for Structural Health Assessment

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***Abstract*- Basic concept of structural health assessment of the structure or structural evaluation is mainly based on visual examination and NDT. The purpose of visual examination is to know the status of structures under applied load and other environmental. Structural health assessments can be made with NDT methods to provide important information for the structural performance of the concrete, rebar location etc. There are different NDT Techniques for assessment of concrete quality e.g. Rebound Hammer, Ultra Sonic Pulse Velocity, Impact-echo etc. Sonic- Integrity Test (SIT) & Pile Integrity Tester is based on principle of Impact-Echo. Rebound hammer can be used to find hardness of the concrete structure surface, and its strength is related using inbuilt calibration curve in the instrument. Ultra-sonic Pulse Velocity Equipment can be used to observe wave transmission through Concrete structure.**

The Present paper includes the study of correlation of experimental studies with laboratory results. The objective of overall investigation is to assess the existing quality, integrity and compressive strength of concrete in the raft, beam, column and superstructure element. This can be utilized for overall structural safety appraisal of the structure. Besides, in case of any inadequacy in the concrete quality being revealed, suitable remedial measures can also be suggested.

***Keywords*- Structural Health Assessment, Rebound Hammer, Ultra Sonic Pulse Velocity, ESR/Elevated Service Reservoir**

I. INTRODUCTION

NDT of concrete is a relatively immature discipline. Because of the two main reasons, the first is the heterogeneous nature of concrete, which makes detection of defects difficult to separate from naturally occurring inclusions and the second reason is immature nature of concrete.

Non-destructive test methods are used to determine hardened concrete properties and to evaluate the condition of concrete in deep foundations, super structure element, bridges, buildings, pavements, dams and other concrete constructions. Non-destructive testing is defined as testing that causes no structurally significant damage to concrete. It does not damage 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 of concrete becomes necessary under many circumstances, such as a natural calamity, fire or an aggregative environment may damage the structure and residual strength may need to be ascertained. NDT methods can be used to estimate the in place strength, quality of concrete and degree of deterioration due to overloading, failure, chemical etc. or environmental attack etc. NDT methods are applied to concrete construction for four primary reasons i.e. Condition evaluation of older concrete for rehabilitation purpose, Quality control of new construction, troubleshooting of problems with new construction and Quality assurance of concrete repairs.

II. PROBLEM STATEMENT

The ESR[1] at Jimme Ki Dhani, Ramsar, Barmer India started in about July 2016. The ESR designed, vetted and approved at competent level for staging of 20 m and capacity of 250 KL. It was planned as an Intze type tank. Bottom ring beam reinforcement cage prepared by the firm and still awaited for checking from the competent level and further construction is stopped. According to Tender stipulation stair case from first bracing and first braced with roof slab is constructed at site. It was reported that the construction of ESR up to fourth bracing was taken up in August 2016. The height of bracing (c/c) from bottom level is 4.42, 4.12, 4.12, and 4.12 & 3.57 m. Every bracing height was completed in three lifts. Reinforcement Detail and Quality of Concrete Pertaining to ESR is suspected, Copy of SBC, mix design and record of site testing were made available.

During site testing some of data which could be gathered are: 6 columns in plan, Size of brace beam 450 mm x 300 mm, Height of first brace (from its bottom) 4.42 m, Dia of Column 450 mm. In the SBC test report value of SBC in t/m^2 by shear failure criteria at 1.5m is given as 8.43 t/m^2, by settlement criteria 9.74 t/m^2 (Peck et al) & 8.93 t/m^2 (IS :8009). Recommendation of foundation depth is not available and SBC at 02 Boreholes conduced. Strata of subsoil is defined as dune sand up to 8.00m. Seismic Zone III considered for design purpose. .

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.

ESR at Jeeme Ki Dhani is constructed at sloped ground. No plinth protection is proposed in drawing.

III. 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.

IV. NDT RESULTS

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

Table-I Results of Bar Locater Test at Jimme Ki Dhani ESR

Member	Details of Reinforcement as Per Drawing	Details of Reinforcement as Per Investigation
TB 3/1 C2-C3	25 mm#03, Nos at Top & Bottom Near to Support with 2 legged strips of 8mm @150mm C/C	02 Rebars at Side face (1-Top +1-Bottom) at support with 2 legged strips @148,155,160,135 mm C/C
TB 3/1 C2-C3	25 mm#03, 20 mm#02 Nos at Top & Bottom Near to Mid Span with 2 legged strips of 8mm @100mm C/C	04 Rebars at Side face (2-Top +2-Bottom) at Mid Span with 2 legged strips of @100,90,110,110 mm C/C
TB 3/2 C3-C4	25 mm#03, Nos at Top & Bottom Near to Support with 2 legged strips of 8mm @150mm C/C	03 Rebars at Top face at support with 2 legged strips @160,140,146 mm C/C
TB 3/2 C3-C4	25 mm#03, 20 mm#02 Nos at Top & Bottom Near to Mid Span with 2 legged strips of 8mm @100mm C/C	04 Rebars at Side face (2-Top +2-Bottom) at Mid Span with 2 legged strips of 3 bars in 320mm
TB 3/2 C3-C4	25 mm#03, 20 mm#02 Nos at Top & Bottom Near to Mid Span with 2 legged strips of 8mm @100mm C/C	03 Rebars at Top face at Mid Span with 2 legged strips of 3 bars in 300mm
TB 3/2 C6-C1	25 mm#03, 20 mm#02 Nos at Top & Bottom Near to Mid Span with 2 legged strips of 8mm @100mm C/C	03 Rebars at Top face at Mid Span with 2 legged strips of 3 bars in 310mm
Column-1/5th	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@185mm, 188mm c/c at Mid Span
Column-1/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@153mm, 137mm c/c at Mid Span
Column-2/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@189mm, 186mm c/c at Mid Span
Column-2/3rd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@184mm, 191mm c/c at Mid Span
Column-2/5th	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos
Column-3/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@190mm, 185mm c/c at Mid Span
Column-3/3rd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@190mm, 200mm, 205mm, 186mm c/c at Mid Span
Column-3/5th	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos
Column-4/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@170mm, 195mm c/c at Mid Span & 8mm@95mm,105 mm c/c at Corner
Column-4/3rd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos
Column-5/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@178mm, 195mm c/c at Mid Span
Column-6/2nd	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos
Column-6/4th	20mm# 12 Nos with strips of 8mm@190mm c/c at Mid Span & 8mm@100mm c/c at Corner	12 Nos with strips of 8mm@160mm, 170mm c/c at Mid Span

Table-II Results of Rebound Hammer Test at Jimme Ki Dhani ESR

Member	Minimum Rebound No.	Maximum Rebound No.	Standard Deviation	Average Rebound No.	Related f_{ck}

P-1 Vertical	23	27	1.8	25.4	17.8
P-1 Horizontal	32	41	3.6	37.2	37.4
P-2 Vertical	23	26	1.4	24	15.7
P-2 Horizontal	17	22	2.1	20.4	10.5
P-2 Horizontal	19	22	1.2	20	9.9
P-2 Vertical	24	29	1.8	26.4	19.4

Table-III Results of Ultrasound Pulse Velocity Test at Jimme Ki Dhani ESR

Member ESR Raft	Length mm	Time µ sec	Velocity m/sec	Value of R considered from RH
Position 1 (ID)	300	107.2	2800	24
Position 2 (ID)	300	106.9	2810	24

Table-IV Results of Rebound Hammer Test at Jimme Ki Dhani ESR

Member ESR Super Structure	Minimum Rebound No.	Maximum Rebound No.	Standard Deviation	Average Rebound No.	Related f_{ck}
TB-3/1 (C1-C2)	34	40	2.4	37.2	37.4
TB-3/1 (C2-C3)	36	40	1.5	38.4	39.5
C-2/3	36	43	2.6	39.2	41
C-3/3	35	41	2.3	37.2	37.4
C-4/3	32	48	5.9	38.2	39.2
C-4/3	40	47	3.9	42.6	47.4
TB-3/2 (C3-C4)	44	51	2.9	48.2	58.4
TB-3/2 (C3-C4)	43	52	4.0	47.4	56.8
TB-3/2 (C3-C4)	40	46	2.8	43.4	48.9
TB-3/2 (C4-C5)	35	41	2.7	38.4	39.5
C-5/2	35	43	3.2	39.6	41.7
TB-3/2 (C5-C6)	25	38	5.1	33.6	31.1
TB-3/2 (C5-C6)	29	37	3.0	32.8	29.7
C-6/2/2nd Lift	37	48	4.7	39.8	42.1
C-6/2/2nd Lift	33	37	1.7	34.4	32.5
C-5/2/2nd Lift	31	39	3.5	35.4	34.2
C-4/2/2nd Lift	35	38	1.3	36.6	36.3
C-4/2/2nd Lift	26	42	6.3	36	35.2
C-4/2/2nd Lift	37	40	1.5	38.4	39.5
TB-3/1 (C6-C1)	27	44	6.5	38.2	39.2
TB-3/1 (C6-C1)	34	40	2.4	37.2	37.4
C-1/1/1st Lift	33	39	2.3	35.0	37.5
TB-3/1 (C1-C2)	35	43	3.1	37.6	38.1
C-3/1/2nd Lift	35	45	3.9	41.8	45.8
C-3/1/2nd Lift	40	43	1.3	41.2	44.7
C-4/1/3rd Lift	29	37	3.6	32.8	29.7
C-4/1/3rd Lift	36	48	4.8	40.8	44.0
C-4/1/3rd Lift	35	46	4.0	40.8	44.0
C-4/1/3rd Lift	39	45	2.3	41.2	44.7

Table-V Results of Ultrasound Pulse Velocity Test at Jimme Ki Dhani ESR

Member	Length mm	Time µ sec	Velocity m/sec	Value of R considered from RH	Combined Compressive Strength σ N/mm ^{2}
C-4/2/2nd Lift (D)	450	105.7	4260	35	28.1
C-4/2/2nd Lift (ID)	300	104.7	2870	35	-
TB-3/1 (C1-C2) (D)	300	73.4	4090	37	
TB-3/1 (C1-C2) (ID)	300	87.6	3430	37	

V. RESULTS BY PHOTOMETER

- At TB3/2 C4-C5 (Near to Junction Upper Face) bar diameter is traced as 24.9.
- At TB3/2 C4-C5 (Near to Mid Span Bottom Side Face) bar diameter is traced as 28.5 which indicates overlap of 20mm & 8mm bars.
- At TB3/2 C4-C5 (Near to Mid Span Bottom Side Face) bar diameter is traced as 41.5 which indicates overlap of 20mm & its development bars.
- At C5/3-4 (Near to Mid Hieght) bar diameter is traced as 18.2.
- At C5/3-4 (Near to Mid Hieght) bar diameter is traced as 9.1mm.

VI. TESTS AT LABORATORY

Few sample casted at actual time of construction provided by your team tested at laboratory to establish the correlation between NDT results and actual destructive test. Rebound Hammer, UPV and Compressive strength test carried out at our laboratory and test results are as follows.

Table-VI Results of Rebound Hammer Test at Laboratory

Laboratory Specimen	Minimum Rebound No.	Maximum Rebound No.	Standard Deviation	Average Rebound No.	Related f_{ck}
Cube 1/ Raft / 14.07.16	28	37	4.1	31.8	28.0
Cube 2/ Raft / 14.07.16	25	36	4.0	31.2	27.0

Cube 3/ Raft / 14.07.16	25	31	2.4	28.0	21.9
Cube 3/ Raft / 14.07.16	25	35	4.6	28.6	22.8
Cube1/Column/13.08.16	27	34	2.5	30.6	26.1
Cube2/Column/13.08.16	29	34	2.0	31.0	26.7
Cube3/Column/13.08.16	25	37	5.2	30.8	26.4
Cube3/Column/13.08.16	24	32	3.4	30.0	25.1
Cube1/Beam/ 08.08.16	30	36	2.6	32.6	29.4
Cube2/Beam/ 08.08.16	27	32	2.3	30.0	25.1
Cube3/Beam/ 08.08.16	28	37	3.4	32.4	29.0

Table-VII Results of Ultrasound Pulse Velocity Test at Laboratory

Laboratory Specimen	Length mm	Time µ sec	Velocity m/sec	Value of R considered from RH	Combined Compressive Strength σ N/mm ^{2}
Cube 1 / Raft / 14.07.16 (D)	150	35.6	4210	30	25.1
Cube 2 / Raft / 14.07.16 (D)	150	35.3	4250	30	26.2
Cube 3 / Raft / 14.07.16 (D)	150	37.2	4030	30	19.8
Cube 1/Column / 13.08.16 (D)	150	38.4	3910	30	17.3
Cube 2/Column / 13.08.16 (D)	150	35.6	4210	30	25.1
Cube 3/Column / 13.08.16 (D)	150	35.4	4240	30	25.9
Cube 1 / Beam / 08.08.16	150	34.1	4400	31	30.8
Cube 2 / Beam / 08.08.16 (D)	150	35.7	4200	31	25.1
Cube 3 / Beam / 08.08.16 (D)	150	34.9	4300	31	27.9

Table-VIII Results of Rebound Hammer Test at Laboratory

Laboratory Specimen	Cube Compressive Test Result
Cube 1/ Raft / 14.07.16	30.22
Cube 2/ Raft / 14.07.16	33.55
Cube 3/ Raft / 14.07.16	27.55
Cube1/Column/13.08.16	30.86
Cube2/Column/13.08.16	29.55
Cube3/Column/13.08.16	32.02
Cube1/Beam/ 08.08.16	31.42
Cube2/Beam/ 08.08.16	28.68
Cube3/Beam/ 08.08.16	31.18

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:-

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

(b) 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 a 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.
- 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 didn't 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. SUGGESTIONS

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

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.

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