Relevance of appropriate Condition Assessment techniques for understanding of deterioration of concrete structures- Some Case Studies

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Abstract - India has witnessed phenomenal infrastructural development during last decade. The rate at which constructions are carried out has resulted in requirement of retrofitting or rehabilitation of many structures. Structures constructed in last around fifty years are also subjected to deterioration due to environmental effects and many other reasons. Techniques normally adopted for condition monitoring of structures are well-known to consultants, retrofitting or rehabilitation is done on assessment of condition of structures using one or many techniques. Adopting single technique, avoiding assessment of level of corrosion and improper interpretation of results may affect the rehabilitation measures or may lead to further deterioration. This paper is based on two case studies; it justifies the relevance of more condition assessment techniques for understanding the level of deterioration of concrete structures.

Key Words: Carbonation, Corrosion, Condition Monitoring, Condition Assessment Techniques

I. INTRODUCTION

In recent times, the country has witnessed phenomenal infrastructure development. Many big concrete structures have been constructed at very faster rate. In addition to existing structures, great need is realised to assess and monitor conditions of reinforced concrete structures. Forensic Civil Engineering as also being recognized as a premier upcoming area having wide range of links with conditional assessment of structures.

For the condition assessment of structures, careful visual inspection of structures [1,2,3] and combination of various techniques is desired to properly understand the conditions of structures and the root causes of deterioration [5,6,7,8]. Deriving conclusions based on selected few tests may lead to inappropriate assessment of structural conditions. Cracks in concrete, causes of the development and propagation and their relevance in understanding of condition of structures is essential before planning adequate retrofitting measures [4].

Carbonation of concrete and carbonation induced corrosion are very significant from deterioration of structures point of view [10,11].

UPV method may be used for applications like evaluation of strength of concrete, uniformity of concrete, quality control during construction, investigations and survey for pre-stressed structure, estimation of damages does to fire or due to environmental impacts, deterioration of concrete due to chemical attach or due to chloride ingress near sea shore etc. In case of fire damages or deterioration of concrete due to chemical attack, the pulse velocity reduces depending upon the severity of the attack and thus by knowing base UPV on unaffected region it is possible to estimate the damages [3]. Resistivity approach and its relevance in understanding reinforcement corrosion rate also help in providing anti corrosion methodologies for preventing concrete distress [9]. The case studies presented indicate relevance of more than one condition assessment techniques as well as carbonation and corrosion related distress in concrete structures.

1.1 Experimental Investigations

The techniques normally used for conditional assessment of structures are listed in Table 1.

Two structures were chosen as case studies for understanding the deterioration of structures and effectiveness of assessment techniques. Extensive tests were carried out, focus was given in choosing appropriate techniques and appropriate structural members. Details of the investigations are presented in various sub sections.

1.2 Case Study 1

An industry of Farm Equipment Sector constructed during 1967-68 was considered as Case Study 1. This building is used for machinery required for manufacture of Farm Equipments. The Building 1 consists of

i) R.C. column with precast R.C. beams, Precast R.C. Purlin and A.C. sheets.

ii) R.C. column with cast in situ beams & R.C. Slab.

The building 2 is Accounts building with R.C. Columns and R.C. conical dome, R.C. rainwater drains connecting conical domes, precast concrete portals.

Based on the physical examination it was decided to use appropriate techniques and tests for understanding condition of structural elements. During the visual inspection it was observed that the beams of R.C. drains are subjected to cracks. But the depths of crack were measured up to 8 to 10 mm only from surface top.

1.2.1 Ultra Sonic Pulse Velocity tests:

The results of Ultra Sonic Pulse Velocity techniques are shown in Table 2.

It was observed that except main columns, the estimated compressive strength of structural members investigated is far below accepted norms.

1.2.2 Rebound Hammer techniques:

The rebound hammer tests were conducted on the same place where U.P.V. is measured, on all structural elements. The results of Rebound Hammer techniques are shown in Table 3.

It is observed that though the estimated strength of concrete is relatively lower, through rebound hammer tests it gives prediction of acceptable level of compressive strength.

1.2.3 Study of alkalinity of concrete

To understand depth of carbonation alkalinity study was carried out on selected structural elements. It has been observed that all the sample holes have a surface pH between 8.51 to 10. Hence the alkalinity of concrete is reduced; thereby the concrete is carbonated. Passive film on reinforcement is destroyed and the corrosion has started in the reinforcement. pH, carbonation, humidity have a direct relationship with the corrosion of rebars. The humidity at the time of taking sample was 71 to 85 %.

The depth of carbonation was measured by phenolphthalein indicator in the holes drilled on non-carbonated concrete. It was observed that the samples turned pink and the depth of carbonation was found to be between 22 mm to 40 mm. Theoretical depth of carbonation is 68 mm.

1.2.4 Gravimetric Method (Weight Loss)

Samples of corroded steel were taken for different diameter from columns, beams and slab where Half Cell potential was measured. These samples were analyzed in the Laboratory. The rate of corrosion is given in Table 4.

1.2.5 Comparison of Linear Polarisation Method & Gravimetric Method

Plant 1

1. *Slab:* - Rate of corrosion (mm/year) is very high by gravitation (3LP) method Deviation is 32%. This value is high due to presence of acid fumes.
2. *Columns:* - Rate of Corrosion (mm/year) is very high due to presence of CO_2 for long time. Deviation is 2.5 times 3LP. This is due to spalling of concrete and increase volume of steel and conversion into oxide.
3. *Beams:* - The rate of corrosion (mm/year) for beam is high due to presence of Sulphuric acid fumes 2.11 times of 3LP. This is due to spalling of concrete increase of volume of steel & oxide formation.

Five concrete cores as per ACI 437 R-91 were taken. The sampling is done by Hilti's Core Cutting machine. (ASTM 42) Diamond studded core bits were used. Some cores were with corroded reinforcement. From the tests of concrete core as per IS 516, the following results can be interpreted.

a) Average U.P.V. is 13N/mm^2.
b) Concrete is of poor quality.
c) Depth of carbonation is 20-40.
d) pH of Concrete of core is 8.2 to 8.8
e) There are internal Cracks.
f) There is deterioration of concrete for accounts building.

These results are very nearer to other tests done. All results of strength and Durability are not within the Permissible Limit as per IS 516 1999 and IS 456-200.
Core results are supplementary for rehabilitation of R.C. structure.

1.2.6 Concrete cover tests

The cover provided is small and cover of slab beam has fallen and column cover can be measured by vertical crack along reinforcement.

1.2.7 *Moisture Profile of Concrete*

On the core taken from R.C. structure, the moisture measurement was taken keeping the core in oven at 100o C for 24 hours. The density of concrete is reduced by 3%.

1.2.8 Observations on case study 1:

From the tests carried out for Strength Durability Stability on plant 1 building and accounts building, the following points can be observed.

Plant 1 Building with Precast beams and A.C. Sheets roofing

1. The condition of R.C. columns is satisfactory. The strength of R.C.C. is marginal.
2. Corrosion of reinforcement has started and service life (rehabilitation) is over.
3. Joints of precast beams and columns have opened.
4. Precast beams conditions and strength is satisfactory.
5. Precast beam portal frame joints have been distorted.
6. Precast beam are going out of plumb
7. Condition of R.C. precast Purlin is satisfactory.
8. Most of A.C. roofing sheets have cracked.
9. All the R.C.C. rain water roof gutter is deteorated steel is corroded and having heavy leakage.

Plant 1 Building with R.C.C. Beams and Slab

1. Overall condition of columns beams gutters slab is unsatisfactory and the strength of concrete is below the accepted value.
2. Slabs and beams are carbonated and corrosion of reinforcement has started.
3. Alkalinity of concrete is lost.
4. Service life is over.
5. Joints with precast building gutters are damaged.
6. All columns are carbonated.

Accounts Buildings

1. All the columns are carbonated.
2. All beams supporting conical dome are damaged concrete deteriorated and heavy corrosion has started.
3. The conical dome reinforcement is corroded spalling of cover has started.
4. Complete conical slab is carbonated with a leakage.
5. Strength, Alkalinity of conical slab is lost.
6. Drains cantilever beams are deteriorated and corroded spalling has started.
7. All conical domes are unserviceable.

2.2 Case Study 2

For Case Study 2, the R.C. structure of a cement factory was constructed before 20 years. The structure is having heavy columns, deep beams and large foundations. Line diagram and various drawings have prepared to identify the structural elements. The R.C.C. part of structure was designed as per the industrial building norms at the time of design.

2.2.1 Ultra Sonic Pulse Velocity

The report on Ultra Sonic Pulse Velocity Analysis on randomly selected points is shown in Table 6.

Observations:

1. For Mill No. 3, column strength is poor. Average compressive strength is 11 N/mm^2 and average U.P.V. is 3.11 km/sec.
2. Concrete strength for beam over column 5 to 8 is 21.2 N/mm^2 and average U.P.V. is 4.48 km/sec.

2.2.2 Rebound Hammer Test

The rebound hammer tests were conducted on the same place where U.P.V. is measured, on all structural elements. The average rebound hammer number is 40 and hence with co-relation graph probable compressive strength of concrete is between 22 N/mm2 to 25 N/mm2 i.e., M 25 grade of concrete.

From the U.P.V. measurement following probable strengths and U.P.V. is tabulated.

Observations:

1. The strength of concrete is around M11 as per (IS-456-2000)
2. Homogeneity of concrete is average
3. Concrete is porus up to 12 to 15% porus.
4. Density of concrete is reduced
5. Water cement ratio is high.

2.2.3 Carbonation of Concrete

Reinforced cement concrete contains calcium oxide (CaO) about (60 to 65%) and when it sets by the chemical reaction becomes calcium hydroxide Ca(OH)2 and calcium silica hydrate jel (C-S-H). The concrete is alkaline having pH 13 to 13.5 and it form a protection oxide film over the reinforcement to protect from corrosion. The atmosphere contains 0.033% of CO2. This CO2 slowly enters the concrete through concrete cover, which contains pours.

The average depth of carbonation is found to be 15mm to 28mm as measured by phenolphthalein indicator.

2.2.4 Study of pH (Alkalinity)

It has been observed that all the sample holes has a surface pH between 9 to 10.1. Hence the alkalinity of concrete is reduced thereby the concrete has carbonated. Passive film on reinforcement has started to degrade and corrosion may also start. pH, carbonation, humidity have a direct relationship with the corrosion of rebars. The humidity at the time of taking sample was as given in table 5.

2.2.5 Dr. M. Pourbaix Atlas

Positive and negative potential with pH greater than 8.0 is corrosion stage. pH less than 7.0 shall have acidic reaction. This may also refer for the Ultra Tech Cement Industry. The pH has reduced form 13 but within the range of 9.0 to 11.99 i.e., carbonation is heavy, but acidic effect cannot be claimed.

2.2.6 Observations on case study 2:

1. No deformation of structure, in cement mill.
2. No angle change of slab and beams, which were observed for N.D.T.
3. No change of geometry of columns and beams.
4. Modulus of elasticity has changed from original value.

II. DISCUSSION

The investigations of two case studies presented indicate the significance of multiple tests in understanding the condition of structures.

In the Case Study-1 presented, it is observed that the results of Ultrasonic Pulse Velocity and Rebound Hammer are varying significantly. If the interpretations are drawn on single test, the predictions would have been inappropriate and might have lead to inconsistent retrofitting measures.

Further the carbonation studies and corrosion, especially in the conical dome part indicate that, the rebar corrosion, its level and its effect on surrounding concrete may hamper the results obtained by different Non Destructive Test techniques. This also suggests more relevance of visual inspection, corrosion studies and the crack propagations before drawing conclusions on NDT techniques.
The Case Study 2, clearly indicates the importance of regular condition monitoring of structures so that retrofitting measures can be immediately taken to prevent further distress in the structures. It is also realized that, there is a need to develop clear-cut plan of action for testing of structural members and execution in the defined time frame is essential.

III. CONCLUSIONS

1. Careful visual inspection of structural members including crack development and propagation and preparation of the schedule of testing is essential.
2. Multiple condition assessment techniques must be adopted as single or few techniques may lead to inappropriate condition assessment of structures.
3. Regular condition assessment of structures is essential to counter further development of distress in the structures.
4. Appropriate interpretation of observations of carbonation penetration and corrosion level is also very significant from condition assessment of structures.

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Table 1

S.N.	Name of Test	Assessment Parameters
1.	Ultra Sonic Pulse Velocity	Probable Compressive Strength
2.	Schmidt Hammer Test	Probable Compressive Strength
3.	Half Cell Potential	Probable Corrosion Of Steel.
4.	3LP & 4 LP Method	Rate Of Corrosion
5.	Crack Profile	Cracks
6.	Core Tests As Per IS S 16	Correlation of test results Obtained.
7.	Carbonation	Depth of Carbonation & Reduction of pH
8.	pH	Alkalinity of Concrete
9.	Moisture Content	Moisture in Concrete
10.	Gravimetric Tests	Weight Loss of Steel Due to Corrosion.
11.	Cover meter Test	Cover by Profometer.
12.	Dr. Pourbaix Diagrams	Corrosion of Steel

Table 2

Type of Building	**Section**	**Structural Element**	**No. of element**	**Average U.P.V. (km/sec)**	**Probable Compressive Strength (N/mm^2)**
Plant 1	Engine Supply Section I	Roof Column	RC1 TO RC 11 (29 Nos)	3.64	14
		Roof Beams	10 Points	3.08	5
	Engine Supply Section II)	Roof Columns	Col. RC 12 to RC39 (51 points)	3.70	16
		Roof Beams	RB 11to RB 35 (17 point)	3.90	18
	Union Office, Engine Supply Motors Engine Supply Section	Slab column	SC 1 to SC 45 (68 point)	2.80	5.0
		Slab Beams	SB 5 to 17 (8 Nos)	3.31	8
Account Building	Account office	Column	A 1 to A 36 (36 point)	2.46	<5 N/mm^2
		Conical Slab Beams	A 10 to A 27 (18 point)	2.53	<5 N/mm^2
			PS_4 to PS_{20}	1.75	<5 N/mm^2

Table 3

Type of Building	**Section**	**Structural Element**	**No. of element**	**Rebound No.**	**Probable Compressive Strength (N/mm^2)**
Plant 1	Engine Supply Section I	R.C.C. Column	Column 1 to 11 Total point 33	40	15 to 18
		R.C. Roof Precast Beams	RB 1 to RB 11, 21 NOS	35	13 to 15
	Engine Supply Section II+ AVL. Eng.	R.C. Column	12 to 39 (75 points)	42	16 to 18
	Union Office, Engine Supply Motors Engine Supply Section	Slab column	Sc 1 to Sc 45 (135 point)	30	14 to 15
Account	Account office	Column	Col. A 1 to A 36	22	12 to 14

Building			(point 188)		
		Conical Dome	Slab beams 60 points	20	12 to 14

Table 4

Type of Building	Structural Element	Description of corrosion level
Plant 1	Columns	The rate of corrosion for rebars of column is 0.46 $gm/day/cm^2$
	Beams	The rate of corrosion is 1.31 x $10^{-5}gm/day/cm^2$
	Slabs	The rate of corrosion is 0.46 $gm/day/cm^2$
Accounts Building	Columns	Rehabilitation stage. The corrosion has increased the volume of steel by 3½ times exerting pressure on Concrete Cover and all cover is spalled. Corrosion of rebars is 30 in slab.
	Beams	
	Slabs	

Table 5

Mill No.	**Element**	**Temperature**	**Humidity**
3	Near Column 1, 2, 3	$32.9^{O}C$	30%
	Near Column 4, 5, 6, 7, 8	$32^{O}C$	38%

Table 6

Sr. No.	**Column/ Beam/ Foundation**	**No. Of Points**	**Quality of Concrete**			
			Excellent	**Good**	**Medium**	**Doubtfu l**
1.	Column 1	3	-	1	2	0
2.	Column 2	8	-	-	6	2
3.	Column 3	6	-	3	2	1
4.	Column 4	8	-	1	6	1
5.	Column 5	3	-	2	1	-
6.	Column 6	5	-	2	3	0
7.	Column 7	7	-	2	3	1
8.	Column 8	7	-	4	2	1
9.	Beam 1 over columns 5, 6, 7, 8	10	1	8	1	-
10.	Beam 2 over columns 8, 9, 10	7	2	-	5	-

Photographs for Plant 1

	
Slab beam section with distorted joint	Plant damaged gutter
 	 
Column RC 18 crab tests, potential carbonation crack column	Sc 29 very corrosion, Distorted joint Crack due to carbonation precast beams
	
Corrosion of bar Accounts Office	Conical slab corrosion spalling A/C building
	
View conical domes damaged concrete	N.D.T. conical dome

Photographs for Case Study 2

N.D.T. of [illegible]

Damaged Tail End

Foundation Tail End

Carbonation of Concrete

Carbonation of Concrete

	
Column NDT in Progress	Rebound Hammer Test