Health Assessment and Retro-fitting of RCC Structures

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Abstract--- *At the time of strengthening the most important parameter of its strength and durability depending upon the structures. In this experimental investigation of nondestructive testing (NDT) is to obtain properties of in place specimens without the destruction of the specimen or the structure and also the study the strength, corrosion, crack monitoring of structural elements and effect of reinforcement on the obtained results. These Non Destructive Instruments were then used to test the columns, beams and slabs. To calculate the strength and durability without destructing it, using Rebound Hammer and Ultrasonic pulse Velocity Test.*

Keywords--- *NDT, Rebound Hammer, UPV, RCPT, and Corrosion.*

I. Introduction

CONCRETE construction is generally expected to give trouble free service throughout its intended design life. However, these expectations are not realized in many constructions because of structural deficiency, material deterioration, unanticipated over loadings or physical damage. Premature material deterioration can arise from a number of causes, the most common being when the construction specifications are violated or when the facility is exposed to harsher service environment than those expected during the planning and design stages. Physical damage can also arise from fire, explosion-as well as from restraints, both internal and external, against structural movement. Except in extreme cases, most of the structures require restoration to meet its functional requirements by appropriate repair techniques.

Non-destructive evaluation (NDE) of concrete and components are well known and extensively used. While they are very good tools for establishing quality levels in new constructions, applying these techniques to damaged structures requires certain level of experience and understanding of limitations of these methods. Solving the problem successfully is entirely dependent on the ability of a team of experts engaged to do this job. Both field and laboratory tests are available. It is important to select the appropriate Non Destructive Evaluation(NDE) techniques and location of investigation.

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Various options in terms of techniques and repair materials are available for executing repair jobs. Selecting a most appropriate material and repair methodology is very important to achieve durable, effective ad economic repairs. Matching the response of repaired sections with the main structures is an important task. Just as building durable construction requires understanding of structural engineering, material science, and environment/exposure conditions, repair jobs also require the same level of attention in these areas.

Familiarity with repair methodology and repair materials is very essential. General civil engineering practice does not offer much scope in this area. The engineer undertaking such specialised jobs should have good knowledge of new materials, repair mythologies, its limitation and the fund a mental of structural engineering to ensure safety and serviceability of the buildings during repair and thereafter.

II. Objective of Work

1. To assess the condition and extent of deterioration/ damage in the RCC framed structure of NPK-Bulk building.
2. To suggest the detail structural strengthening/ rehabilitation/scheme to structural elements of the building for safe functioning.

III. Case Study

This is a report on ‘condition assessment of existing RCC structure of NPK-Bulk go-down at Zuari Agro Chemicals Limited, Goa, by using non-destructive/partially-destructive testing, visual inspection survey and laboratory testing of concrete.

The fertilizer plant of the Zuari Agro Chemicals Limited is located on the western coast of India on the Arabian sea-shore in the state of Goa. The NPK-Bulk building is a typical RCC column-beam framed structure having sloped roofing system with reinforced concrete pre-cast trusses and purlins. The building has seven bins on east side and as many on the west side, and two conveyor belts running over the bins at 1^{st} floor level.

Accordingly, after accepting the assignment, visual inspection survey of the structure, sample collection for laboratory analysis and field testing on select locations of RC members of the structure were carried out from to assess the extent of deterioration, reinforcement corrosion, quality and strength of concrete in the structure. The laboratory analyses of collected samples were carried out for various concrete properties.

Visual Inspection Survey

Visual inspection conducted was an examination of the structure for the purpose of identifying areas of deteriorations/damages. It is referred in connection with survey of RCC members and elements of the structure that are showing signs of deterioration /damages.

The following were the observations of the visual inspection survey of the structure covered under study.

1. Severe cracking & spalling of concrete, exposure of corroded reinforcement bars, etc was observed at many locations.
2. RCC partition walls and front columns of the bins were observed to be severely damaged though they are protected by about 150 mm thick additional RCC encasement up to a height of about 2.0 M.
3. The heavy earth moving equipment used inside the building for material handling, cause mechanical damages to the RCC elements. These damages over a period of time have become severe at many locations.
4. Reinforcement corrosion and related deterioration, such as cracking & spalling of concrete, exposure of rebars, etc even in the pre-cast trusses was observed.
5. The supporting RCC beams and slabs for conveyor system were observed to be severely damaged and in distressed condition due to severe rebar corrosion.
6. Steel structure used for supporting the conveyor belt system was also observed to be experiencing corrosion.
7. It was learnt that the roofing system is recently repaired and replaced with new roof sheets and purlins.

Rebound Hammer Test

The rebound hammer test is based on the principle that a calibrated standard mass rebounds off a hard surface in repeatable manner if impacted with standard force. The rebound hammer index or number is considered to be an indicator of the quality of cover concrete. This test is also useful in comparing the quality of concrete from one location to another indicating the homogeneity of the concrete in the structure. Normally it is not very accurate in predicting the compressive strength, but taken together with the more definitive test of core samples, the rebound hammer result can be an indicator of the compressive strength. The rebound hammer test using a standard Schmidt Hammer from M/s CNS FARNEL- England as per IS: 13311 - (Part - II) - 1992 - (Reaffirmed in 2004), was carried out on select RCC members of the building. Fig.1 shows the Rebound Hammer test in progress. A minimum of eight readings were recorded from each location and the average was calculated after omitting the very low and very high readings, if any. The results of the rebound hammer test are tabulated in Table 1. Please refer Fig.11 for identification of test locations.

Figure 1: Rebound Hammer in Progress

Table 1: Rebound Hammer Test Results

Sl. No.	Location ID	Rebound Hammer Readings	Avg. RH Index	Estimated Compressive Strength, MPa
1	Column-C4, Gr. Lvl.	30 38 36 34 36 38 36 34	35	28
2	Do	34 36 38 38 34 36 34 40	36	29
3	Do	38 34 36 34 38 44 40 36	38	32
4	Do	34 38 30 36 34 38 30 32	34	27
5	Column-C5, Gr. Lvl.	40 36 38 36 34 32 34 40	36	29
6	Do	38 30 38 30 36 34 38 30	34	27
7	Do	36 38 36 34 32 38 32 34	35	28
8	Do	38 34 38 34 36 40 38 36	37	31
9	Column-C6, Gr. Lvl.	36 34 36 34 38 38 32 34	35	28
10	Do	32 34 40 34 36 34 38 36	36	29
11	Do	38 40 36 38 40 36 34 38	38	32
12	Do	36 38 30 36 34 36 30 32	34	27
13	Column-C7, Gr. Lvl.	36 34 32 32 36 34 40 38	35	28
14	Do	34 28 34 28 30 36 34 36	33	26
15	Do	40 32 34 36 34 32 38 32	35	28
16	Do	36 34 42 38 34 36 34 38	37	31
17	Column-C8, Gr. Lvl. (Outside)	28 26 34 28 30 32 28 30	30	22
18	Do	30 32 36 38 36 34 32 38	35	28
19	Do	24 26 28 26 30 28 30 28	28	20
20	Do	26 24 22 28 26 22 24 26	25	16
21	Column-B4, Gr. Lvl.	38 30 36 34 38 42 38 38	37	31
22	Do	36 34 28 30 36 34 34 30	33	26
23	Do	38 34 36 34 32 38 32 34	35	28
24	Do	28 38 34 36 34 32 38 32	34	27
25	Column-B5, Gr. Lvl.	36 34 32 36 34 32 38 30	34	27
26	Do	34 38 36 40 36 38 34 32	36	29

Ultra sonic Pulse Velocity (UPV) Test

Ultra-sonic pulse velocity (UPV) tests are based on the transmission of sound waves through the concrete and measuring the transit time between two well defined points. The pulse velocity is higher for a denser and good quality concrete.

In the present study UPV test was carried out by TICO instrument-Proceq make (Switzerland) as per IS : 13311- (Part - I)-1992- (Reaffirmed in 2004) by Direct and In-direct methods on select RCC members of the structure.Fig.2 shows the UPV test in progress. The results of the UPV test are given in Table-2. Please refer Fig.11 for identification of test locations.

Figure 2: UPV test in Progress

Table 2: Ultra-sonic Pulse Velocity Test Results

Sl. No.	Location ID	Method	Distance, mm	Time, mic-sec	Velocity, km/sec	Quality of Concrete
1	Column-C4, Gr. Lvl.	Direct	600	189	3.17	Medium
2	Do		600	243	2.47	Poor
3	Do		600	NR	-	Deteriorated
4	Do		600	NR	-	Deteriorated
5	Column-C5, Gr. Lvl.	Direct	600	181	3.31	Medium
6	Do		600	260	2.31	Poor
7	Do		600	NR	-	Deteriorated
8	Do		600	NR	-	Deteriorated
9	Column-C6, Gr. Lvl.	Direct	600	252	2.38	Poor
10	Do		600	NR	-	Deteriorated
11	Do		600	NR	-	Deteriorated
12	Do		600	NR	-	Deteriorated
13	Column-C7, Gr. Lvl.	Direct	600	177	3.39	Medium
14	Do		600	263	2.28	Poor
15	Do		600	245	2.45	Poor
16	Do		600	370	1.62	Poor
17	Column-C8, Gr. Lvl. (Outside)	In-direct	300	103	3.06	Medium
18	Do		300	181	1.74	Poor
19	Do		300	153	2.06	Poor
20	Do		300	172	1.83	Poor
21	Column-B4, Gr. Lvl.	Direct	600	251	2.39	Poor
22	Do		600	271	2.21	Poor
23	Do		600	210	2.86	Poor
24	Do		600	209	2.87	Poor
25	Column-B5, Gr. Lvl.	Direct	600	196	3.06	Medium
26	Do		600	212	2.83	Poor
27	Do		600	231	2.60	Poor

Concrete Core Sampling and Testing

Core samples from existing concrete members can be conveniently collected by use of suitable cylindrical drill-bits and tested for compressive strength and other properties. These provide more reliable results of concrete properties in the structures. The Krafteek instrument (German Make),used for the present study was having rotary cutting tool with diamond tip. Core samples of 70and 110 mm diameter and 100 mm length (appox.)were obtained from various locations for not only compressive strength testing in the laboratory, but also for RCPT, carbonation test and chemical analysis of concrete.Fig.3 shows the concrete core extraction in progress and Fig.4 shows the core samples obtained. Please refer Fig.11 for identification of test locations.

The compressive strength as measured from cores gives the best assessment of the concrete strength. The results of tests conducted on cores are given in Table 3.

Figure 3: Core Extraction in Progress

Figure 4: Concrete Core Samples

Table 3: Concrete Core Test Results

S.No.	*Core No.*	*Load in kN*	*Core Compr. Strength #, in MPa*	*Correction factor*	*Corrected Core Strength $, in MPa*	*Equivalent Cube Strength @, in MPa*
1	C-1	49.0	14.15	0.940	13.30	16.6
2	C-2	56.0	16.17	0.910	14.71	18.4
3	C-3	62.0	17.90	0.975	17.45	21.8
4	C-4	47.0	13.57	0.900	12.21	15.3
5	C-5	66.0	19.05	0.990	18.86	23.6
6	C-6	72.0	20.79	0.950	19.75	24.7
7	C-7	61.0	17.61	0.945	16.64	20.8
8	C-8	46.0	13.28	0.915	12.15	15.2
9	C-9	58.0	16.75	0.995	16.66	20.8

Cover Meter Test

The concrete cover to the embedded reinforcement steel in the RCC structures can be measured conveniently by using cover meter instruments which work on the principles of magnetism. The cover meter test was performed with the help of Profometer 5+ instrument-Proceq make (Switzerland) at select locations on the structures to find the concrete cover to reinforcement. The criterion used for adequacy of results is as per structure's exposure condition with respect to the minimum cover mentioned in IS:456-2000 (Reaffirmed in 2011).Fig. 5 shows the Cover meter test in progress. The results of cover meter test are given in Table-4. Please refer Fig.11 for identification of test locations.

Figure 5: Cover Meter Test in Progress

Table 4: Cover Meter Test Results

Location Nos.	Location ID	Concrete Cover to Rebars, in mm				Lowest Cover, in mm
1	Column-B7, Gr. Lvl.	54	51	48	50	48
2	Column-B5, Gr. Lvl.	36	39	41	35	36
3	Column-C5, Gr. Lvl.	40	43	46	36	40
4	Column-C7, Gr. Lvl.	57	45	41	47	41
5	Column-C1, Gr. Lvl. (Outside)	46	58	61	42	42
6	Column-D5, Gr. Lvl. (Outside)	51	61	46	43	43
7	Column-C8, Gr. Lvl. (Outside)	42	46	37	53	37
8	Column-A6, 1st Lvl.	34	38	40	38	34
9	Column-A2, 1st Lvl.	41	40	39	49	39
10	Column-D6, 1st Lvl.	44	47	55	46	44
11	Beam B5-B6, 1st Lvl., Tie Beam	42	41	33	26	26
12	Column-B6, 1st Lvl.	37	36	42	25	25
13	Beam C4-C5, 1st Lvl., Tie Beam	41	44	46	49	41
14	Column-C7, 1st Lvl.	32	34	27	39	27
15	Beam E7-E8, 1st Lvl., Conv. Belt	49	50	52	56	49
16	Beam F5-F6, 1st Lvl., Conv. Belt	40	44	32	37	32
17	Column-C3, 1st Lvl.	37	35	33	42	33
18	Beam B2-B3, 1st Lvl., Tie Beam	42	43	48	51	42
19	Bin Wall C4-D4,	60	64	49	63	49
20	Bin Wall A5-B5,	38	64	45	49	38
21	Conv. Belt Slab b/w A[illegible]-F[illegible]	19	23	25	31	19
22	Conv. Belt Slab b/w E[illegible]-D[illegible]	30	24	22	26	22

Carbonation Test

Carbonation of concrete results from the reaction of atmospheric carbon dioxide (CO_2) with calcium hydroxide {$Ca(OH)_2$} in concrete forming calcium carbonate ($CaCO_3$). The carbonation of concrete is basically a surface zone phenomenon and it results in reduction of pH or alkalinity of the concrete, thus opening the possibility of carbonation induced reinforcement corrosion in the RCC structures. Carbonation should not reach reinforcement level in the structures.

The carbonation test was carried out at select locations as per the guidelines given in BS:1881 (Part 201)–1986. Carbonation depths are simply determined by the use of (1% ethanol) indicator after a freshly broken concrete surface is sprayed by phenolphthalein. Depth of carbonation is indicated by the colourlessness of the test zone in concrete sample and pink colour indicates presence of alkaline concrete. Fig.6 shows the carbonation test carried out on concrete sample. The results of carbonation test are tabulated in Table-5. Please refer Fig.11 for identification of test locations.

Figure 6: Carbonation test on core samples

Table 5: Carbonation Test Results

Location Nos.	Location ID	Carbonation Depth, in mm
1	Column-B7, Gr. Lvl.	15
2	Column-B5, Gr. Lvl.	15
3	Column-C5, Gr. Lvl.	15
4	Column-C7, Gr. Lvl.	15
5	Column-C1, Gr. Lvl. (Outside)	20
6	Column-D5, Gr. Lvl. (Outside)	20
7	Column-C8, Gr. Lvl. (Outside)	15
8	Column-A6, 1st Lvl.	20
9	Column-A2, 1st Lvl.	20
10	Column-D6, 1st Lvl.	20
11	Beam B5-B6, 1st Lvl., Tie Beam	15
12	Column-B6, 1st Lvl.	20
13	Beam C4-C5, 1st Lvl., Tie Beam	25
14	Column-C7, 1st Lvl.	20
15	Beam E7-E8, 1st Lvl., Conv. Belt	20
16	Beam F5-F6, 1st Lvl., Conv. Belt	25
17	Column-C3, 1st Lvl.	20
18	Beam B2-B3, 1st Lvl., Tie Beam	25
19	Bin Wall C4-D4,	20
20	Bin Wall A5-B5,	20
21	Conv. Belt Slab b/w A[illegible]-F[illegible]	20
22	Conv. Belt Slab b/w E[illegible]-D[illegible]	20

Half Cell Potential Test

The Half Cell Potential Measurement test enables the detection of corrosion in reinforcement. Using a standard copper-copper sulphate (Cu/CuSO4) reference electrode, the cell is electrically connected to the reinforcement wherever it is already exposed in case of half-cell potential.

The half-cell potential test was performed with the help of CANIN^{+}instrument-Proceq make (Switzerland) at select locations on the RCC members of the building.Fig.7 shows the Half-cell potential measurements in progress. The results of the half-cell potential measurements are tabulated in Table-6. Please refer Fig.11 for identification of test locations.

Figure 7: Half-cell Potential Test in Progress

Table 6: Half-Cell Potential Test Results

Sl. Nos.	Location ID	Half-cell Potentials, in mV				Remarks
1	Column-C3, Gr. Lvl.	-243	-245	-278	-281	Uncertain
2	Column-C5, Gr. Lvl.	-323	-349	-380	-400	>90% chance of active corrosion
3	Column-C7, Gr. Lvl.	-370	-325	-375	-368	
4	Column-B1, Gr. Lvl.	-300	-307	-328	-317	Uncertain
5	Column-B3, Gr. Lvl.	-343	-258	-388	-353	>90% chance of active corrosion
6	Column-B6, Gr. Lvl.	-220	-220	-198	-201	Uncertain
7	Column-D4, Gr. Lvl. (Outside)	-196	-175	-162	-179	>90% chance of no active corrosion
8	Column-A7, 1st Lvl.	-450	-445	-436	-435	>90% chance of active corrosion
9	Column-A4, 1st Lvl.	-357	-359	-362	-369	
10	Beam B2-B3, 1st Lvl., Tie Beam	-444	-443	-439	-461	
11	Beam B5-B6, 1st Lvl., Tie Beam	-446	-428	-433	-462	
12	Column-B6, 1st Lvl.	-204	-193	-212	-178	Uncertain
13	Beam C4-C5, 1st Lvl., Tie Beam	-370	-289	-345	-350	>90% chance of no active corrosion
14	Column-C7, 1st Lvl.	-328	-303	-278	-247	Uncertain
15	Beam E7-E8, 1st Lvl., Conv. Belt	-436	-487	-447	-289	>90% chance of no active corrosion
16	Beam E4-E5, 1st Lvl., Conv. Belt	-240	-250	-210	-238	Uncertain
17	Beam F5-F6, 1st Lvl., Conv. Belt	-351	-345	-284	-350	>90% chance of active corrosion
18	Column-C3, 1st Lvl.	-354	-281	-289	-347	
19	Bin Wall C4-D4,	-245	-332	-189	-205	Uncertain
20	Column-C6, 1st Lvl.	-481	-481	-490	-507	>90% chance of no active corrosion
21	Bin Wall A5-B5,	-497	-475	-481	-465	
22	Column-B3, 1st Lvl.	-381	-330	-340	-365	
23	Column-B6, 1st Lvl.	-360	-344	-289	-350	
24	Conv. Belt Beam b/w D[illegible]-E[illegible]	-369	-321	-352	-293	

Electrical Resistivity Test

The four probe Wenner technique is used to measure electrical resistivity of concrete which intern to assess the corrosion rate of embedded steel reinforcement in the RCC structures. The electrical resistivity of concrete depends on many factors such as moisture in concrete, pore size, concrete quality, etc. The probes are commonly pointed metals rods equally spaced in a straight line, typically 50 mm apart. A current is applied between two outer probes and potential difference is measured across the two inner probes and then the electrical resistivity of concrete is measured.

Table 7: To Determine the Probabilistic Corrosion Rate Chart.

Resistivity, kΩ-cm	Corrosion Rate
>20	Low
10 to 20	Low to Moderate
5 to 10	High
<5	Very High

The electrical resistivity test was performed with the help of Resipod instrument-Proceq make (Switzerland) at select locations on the RCC chimney.Fig.8 shows the electrical resistivity test is in progress. The results of the resistivity test are tabulated in Table-8. Please refer Fig.11 for identification of test locations.

Figure 8: Electrical Resistivity Test in Progress

Table 8: Electrical Resistivity Test Results

Sl. No.	Location ID	Concrete Resistivity, in kΩ-cm				Remarks
1	Column-C3, Gr. Lvl.	1.5	1.3	2.1	2.9	High to very high corrosion rate
2	Column-C5, Gr. Lvl.	4.1	3.7	4.9	4.5	
3	Column-C7, Gr. Lvl.	4.9	6.0	5.2	4.3	
4	Column-B1, Gr. Lvl.	10.9	11.4	12.2	6.9	Moderate to high corrosion rate
5	Column-B3, Gr. Lvl.	3.9	4.2	3.5	4.4	Very high corrosion rate
6	Column-B6, Gr. Lvl.	3.7	2.8	2.2	1.3	
7	Column-C1, Gr. Lvl. (Outside)	25.0	28.0	32.0	21.0	Low corrosion rate
8	Column-D4, Gr. Lvl. (Outside)	9.5	7.9	8.2	10.1	High corrosion rate
9	Column-A7, 1st Lvl.	7.0	8.2	6.7	7.4	
10	Column-A4, 1st Lvl.	8.0	7.0	6.0	9.9	
11	Beam B5-B6, 1st Lvl., Tie Beam	2.4	3.1	3.8	2.5	High to very high corrosion rate
12	Column-B6, 1st Lvl.	6.6	5.0	4.0	3.2	
13	Beam C4-C5, 1st Lvl., Tie Beam	8.8	6.0	7.0	6.0	
14	Column-C7, 1st Lvl.	5.0	3.0	4.0	2.0	
15	Beam E7-E8, 1st Lvl., Conv. Belt	5.1	4.3	3.9	4.0	
16	Beam F5-F6, 1st Lvl., Conv. Belt	5.9	4.6	4.5	5.4	
17	Column-C3, 1st Lvl.	14.0	10.3	11.1	10.0	
18	Bin Wall C4-D4,	5.4	6.4	9.9	5.3	
19	Column-C6, 1st Lvl.	4.0	4.1	3.8	3.9	
20	Bin Wall A5-B5,	6.3	5.1	4.0	5.3	
21	Column-B3, 1st Lvl.	3.0	2.8	3.0	2.1	Very high corrosion rate
22	Column-B6, 1st Lvl.	3.2	2.0	2.0	2.0	

Rapid Chloride Penetration Test (RCPT)

Chloride ingress is the major form of environmental attack in reinforced concrete which causes early deterioration of structures due to corrosion of rebars. RCPT is an accelerated test method that measures the ability of chloride ions to penetrate in concrete. The method covers the determination of the electrical conductance of concrete to provide its resistance to the penetration of chloride ions. RCPT was carried out on the concrete core samples collected from the structure as per the procedure described in ASTM C 1202 and the following criterion is applied.

Table 9: To Determine the RCPT Chart

Charge Passed, in Coulombs	Chloride Penetrability
> 4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low
<100	Negligible

RCPT was carried out at 25 Degree Celsius in KCPPL, DSIR accredited R&D laboratory, Mahape, Navi-Mumbai. Fig.9 and Fig.10 show the RCPT in progress. The results of the RCPT are tabulated in Table-10.Please refer Fig.11 for identification of test samples.

Figure 9: Samples Prepared for RCPT

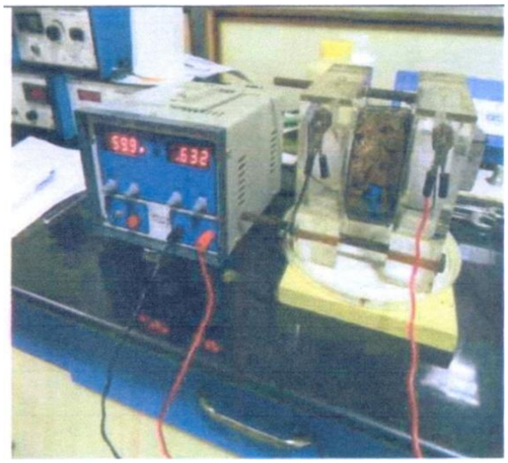

Figure 10: RCPT Set-Up

Table 10: Rapid Chloride Penetration Test Results

Sl. No.	Location ID	Dia of sample, in mm	Density of sample, (Initial Dry Condition) in g/cm^3	pH of sample	Water absorption (96 hrs) in % age	Chloride content in ppm	Charge passed in Coulombs
1	Bin Wall A5-B5	112.50	2.44	9.80	3.90	750	6716
2	Bin Wall A5-B5	112.50	2.34	9.90	4.20	810	6890
3	Bin Wall C4-D4	112.50	2.51	10.0	3.70	960	6562
4	Bin Wall C4-D4	112.50	2.48	8.60	3.80	870	5995
5	Conv. Belt Slab b/w A_{3-4}-F_{3-4}	112.50	2.57	7.70	3.70	1100	7344
6	Conv. Belt Slab b/w A_{3-4}-F_{3-4}	112.50	2.61	8.30	3.50	990	6463
7	Conv. Belt Slab b/w D_{3-4}-E_{3-4}	112.50	2.22	7.90	4.10	950	6200
8	Conv. Belt Slab b/w D_{3-4}-E_{3-4}	112.50	2.55	9.10	3.40	1050	7290
9	Column-B1, Gr. Lvl.	112.50	2.47	9.30	4.30	940	5897
10	Tie Beam C4-C5, 1st Lvl.	112.50	2.39	8.40	4.40	760	6057

Chemical Analysis of Concrete

The chemical analysis of concrete samples was carried out for the determination of (i) Chloride content (ii) Sulphate content and (iii) pH of the concrete. Standard procedures as per the relevant standards, For Chlorides - IS:14959 (Part-II) 2001 (Reaffirmed in 2007), For Sulphates- BS:1881 (Part-124) 1988 and For pH - NCB 9th Intl. Seminar Vol-3 are used for this purpose.

The results of the chemical analysis of concrete are tabulated in Table-11.

Table 11: Chemical Analysis of Concrete

Sl. No.	Location ID	Chloride content (Acid Soluble) (kg/cum)	Sulphate as (SO_3) % by mass of cement in concrete mix	pH of concrete
1	Column-B5, Gr. Lvl.	0.59	0.83	9.54
2	Column-C7, Gr. Lvl.	0.78	0.58	9.62
3	Column-C1, Gr. Lvl. (Outside)	0.47	0.89	9.90
4	Bin Wall C4-D4,	0.71	1.02	9.20
5	Column-C3, 1st Lvl.	0.90	0.94	8.67
6	Column-A2, 1st Lvl.	0.65	0.66	9.48
7	Beam C4-C5, 1st Lvl., Tie Beam	0.82	0.76	8.87
8	Beam B2-B3, 1st Lvl., Tie Beam	0.68	0.85	9.33
9	Beam E7-E8, 1st Lvl., Conv. Belt	0.73	0.79	9.34
10	Beam F5-F6, 1st Lvl., Conv. Belt	0.86	0.98	8.58

IV. Discussions and Recommendations

Physical Properties of Concrete

The physical properties of the concrete in the structure were studied from the test data of the Rebound Hammer test, Ultra-sonic pulse velocity test and the Compressive strength test on the concrete core samples.

The rebound hammer test data along with compressive strengths derived from the standard calibration chart are tabulated in Table-1. Rebound hammer indices of concrete showed a varying surface hardness with rebound indices ranging from 22 to 37, indicating non-homogeneity of concrete in the structure with estimated compressive strengths varying from13 to 31MPa. The low values at many locations were indicative of deteriorations observed in the structure.

The ultra-sonic pulse velocity test was performed by Direct and In-direct methods and the results are provided in Table-2. The concrete in the structure showed the ultra-sonic pulse velocities at non-deteriorated locations ranging from3.0to 4.0 km/sec indicating concrete of medium to good quality. The values less than 3.0 km/sec and no readings at many locations could be attributed to the deteriorations observed in the concrete. The concrete core samples collected from various locations were tested for compressive strength in the laboratory as per the procedure described earlier. The identification of cores and the core test results are tabulated in Table-3.The results on concrete cores showed compressive strength of concrete in the building ranging from 15 to 25MPa.

Corrosion Tests Results

The results of cover meter test given in Table-4 reveal that the concrete cover to rebars in the structure was found to be inadequate with values at many locations less than 45 mm–a minimum requirement for the structures exposed to severe exposure conditions as per IS:456-2000 (Reaffirmed in 2011).

The carbonation test results are given in Table-5 Carbonation depthon measuring by Phenolphthalein spray test on freshly broken concrete was found to be significant with value up to 25 mm.

The Half-cell potential test for reinforcement corrosion was carried out at various locations of the building and the results are tabulated in Table-6. The potentials, numerically more than the threshold value of 350 mVat many tested locations, were indicative of active corrosion of embedded rebar in the RCC elements of the structure.

The Electrical resistivity test of concrete for reinforcement corrosion was also carried out at various locations of the building and the results are tabulated in Table-8. The resistivity values less than 20 kΩ-cm at almost all the tested locations were indicative of high to very high reinforcement corrosion rate in the structure.

RCPT was carried out in the laboratory on the concrete core samples collected from the structure as per the procedure described in ASTM C 1202 and the results are tabulated in Table-10. The measurement of charge passed was found to be much more than 4000 Coulombs in all the tested samples indicating high chloride penetrability in concrete. Estimated chloride content in concrete was found to be 750 to 1100 ppm, i.e., 3 to 4 times more than the threshold limit of 250 ppm. Alkalinity of concrete was also found to be gone down significantly withpH values of concrete between only 7.7 and 9.8. Water absorption in the concrete was also found to be on higher side.

Chemical Analysis Results

The chemical analysis of the concrete samples, for Chloride content, Sulphate content and pH of concrete, prepared from the concrete cores collected from different locations of the chimney were carried out in the laboratory. The identification of samples taken for chemical analysis and the results are provided in Table-11.

The chloride content in all the samples was found to be more than the limiting value of 0.6 kg/cum indicating severe ingress of chlorides in the concrete. The sulphates in the concrete samples were found to be less than the limiting value of 4% by mass of cement in the concrete. The pH values were found to be less than 11 in all the samples of concrete tested indicating the alkalinity of the concrete has gone down significantly. This also confirms the pH measured in RCPT and the carbonation of concrete taken place in the structure.

Recommendations

It is recommended here that all the deteriorated and damaged RCC elements and portions of the building shall be immediately strengthened and the structure shall be given an extensive anti-corrosive anti-carbonation protective measure for its safe working and to increase its durability. It is also recommended that suitable protective measures shall also be provided to vulnerable RCC elements against the mechanical damages.

It is also recommended that the periodic visual inspection/ monitoring of the structure by non-destructive testing for any signs of deterioration and hence, repairs, if any required in the building shall be carried out for its safe working.

The following methodology shall be adopted to repair & strengthen the deteriorated /damaged RCC elements and portions in the building, to provide anti-corrosive and anti-carbonation protective measures and to provide protective measure against mechanical damages;

A. Surface Preparation, Anti-corrosive treatment & Additional Reinforcement, B. Structural Strengthening in Patches using Epoxy Mortar (EPM), C. Structural Strengthening using Micro-concrete Encasement, D. Comprehensive Anti-corrosive Protective Measure to the Building, E. Structural Strengthening using Carbon Fibre (CF) Wrapping, F. Protective Measure for RCC Elements against Mechanical Damage, G. Anti-corrosive Anti-carbonation Protective Coating to Inner RCC Elements, H. Likely Repair & Strengthening Methodology Element wise

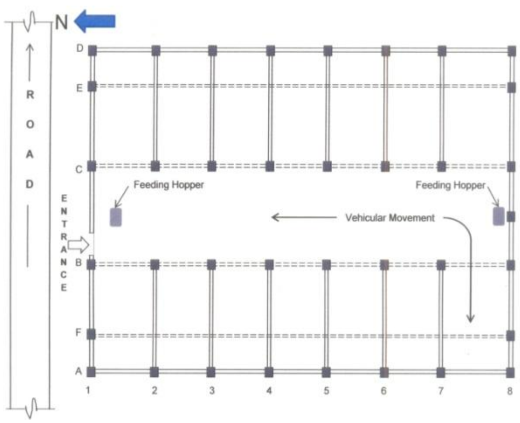

Figure 11: Line Diagram of NPK Bulk go Down Plan (For test location & RCC member identification)

Table 12: Likely Strengthening Methodology

S.No	Members ID, Pl refer Fig. 11		Likely Strengthening Methodology as per 4.2 recommendations
	Ground Floor		
1	Column	B1	A, C, D & G
2	Column	B2	A, B, C, D & G
3	Column	B3	A, B, C, D & G
4	Column	B4	A, B, D & G

V. CONCLUSION

The following conclusions can be drawn on the basis of the findings from visual inspection survey, the tests results and their analysis provided in this report:

1. Rebound hammer indices of concrete showed a varying surface hardness with estimated compressive strengths varying from 13 to 31 MPa, indicating non-homogeneity of concrete in the structure. The low values at many locations were indicative of deteriorations observed in the structure.
2. The results of the ultra-sonic pulse velocity test showed concrete of medium to good quality in few locations of the structure. But, very low values at many locations were indicative of poor quality concrete and severe deteriorations observed in the structure.
3. The concrete core test results showed varying compressive strength of concrete in the building ranging from 15 to 25 MPa.
4. The concrete cover to rebars in the structure was found to be inadequate with values less than 45 mm at many locations.
5. The carbonation of concrete in the structure was found to be significant with carbonation depth measured up to 25 mm.
6. The results of half-cell potential test were indicative of active corrosion of embedded rebars in the RCC elements of the structure.
7. Similarly the results of electrical resistivity of concrete showed high to very high rate of reinforcement corrosion in the structure.
8. The findings of RCPT showed very high chloride penetrability in concrete, significant loss of alkalinity of concrete and hence loss of passive protection of alkaline concrete to rebars against corrosion.
9. There is a severe ingress of chlorides (more than the limiting value of 0.6 kg/cum) in the cover concrete and hence chloride induced rebar corrosion in the structure.
10. Sulphates in the concrete samples were found to be less than the limiting value of 4% by mass of cement in the concrete.
11. The pH of concrete, found to be less than 11 in all the samples of concrete tested indicated the alkalinity of the concrete has gone down significantly, confirming the RCPT and carbonation test results. Thus, embedded rebars in RCC elements of the structure have lost the passive protection of alkaline concrete.
12. As found from the test results, it can be concluded here that the structure is experiencing severe ingress of chlorides, carbonation of concrete, loss of concrete alkalinity, high electrical conductance in concrete, high rate of reinforcement corrosion and severe deteriorations due to rebar corrosion. This was found to be a matter of serious concern as regards to the safe functioning and durability of the structure.

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