Health Monitoring of Existing Reinforced Cement Concrete Structures Using Non-Destructive Tests and Repair Methodology

[1]Aman Kumar, [2]Navdeep Mor
[1]M.E. Student, [2]Ph.D Scholar
Department of Civil Engineering
National Institute of Technical Teachers' Training and Research, Chandigarh, India

Abstract: Sustainable development means the utilization of resources at a rate equal to less than the rate at which they are renewing. In India infrastructure industry is growing rapidly due to globalization, raising awareness and growing importance of Indian globally, simultaneously the concrete repair and rehabilitation is becoming the need of the hour for sustainable development of the country. In the present situation, challenges faced by countries like India are to sustain the existing expectations with limited resources available. There is a lot of demand for repair of damaged buildings and rehabilitation of existing concrete structures. The common structural defects are, cracks, spalling, corrosion, leakage, chloride & sulphate attack, carbonation etc. If such defects were not solved at their initial stages, it will lead to the serious damages to the structures. This paper deals with condition assessment and repair of RCC (G+3) building situated at Udhampur J&K. Rigorous visual inspection followed by detailed distress mapping using the Non-Destructive Tests was carried out for each structural member of building to find out extent and root cause of deterioration. Reinfored concrete (RC) struture may suffer serveral types of defects that may jeoparadise their service life . various techniques are available for repair and rehablitation of reinforeced concrete structures. From maintenance point of view it is essential to take up the strength assessment of an existing structure. So, to find out the resason behind the deteroration of the concrete structures some of the NDT (Non-Destructive Testing) and partially destructive technique are used.

Index Terms – **Visual Inspection, Non-Destructive Testing, Strengthening, Repair and Rehabilitation**

1.1 INTRODUCTION

One of the major requirements in structures is to resist the deterioration due to aging. Structures are constructed at reasonable cost and time. Repair of structures is very expensive. In order to prevent deterioration it is important to have routine assessment of structures without damaging the structure. This mentoring is possible with non-destructive methods. The most commonly sort properties of concrete is its compressive strength, homogeneity of concrete along with corrosion probability. The NDT methods are very useful in carrying out the in-situ condition of RCC structures along with parameters causing deterioration of RCC structures. A case study was carried out to access the levels of deterioration of structures in an RCC Structure located in northern India. Monitoring was carried out through detailed visual inspection along with NDT Techniques to assess the deterioration and plan repair and rehabilitation. Many researchers have used Non-destructive methods such as Rebound hammer & ultrasonic pulse velocity to monitor the extent of deterioration in RCC structures. Carbonation of concrete and corrosion determination is carried out with phenolphthalein indicator and corrosion analyzer.

Ramesh Kumar G. B. in [1] has briefly discussed various NDT techniques such as Rebound Hammer, Ultrasonic Pulse Velocity, Carbonation Test, Rebar Locator Test & Impact Echo Test, from a practical standpoint of an experienced Structural Engineer along with some partial-destructive testing methods of in-situ concrete. The NDT methods indirectly estimate the quality and strength of RCC structures although the estimated strength is comparable with destructive test results. Therefore, it is advisable to perform more than one tests.

J. Bhattacharjee in [2] has highlighted the present state of maintenance especially in developing country like India and about the utilization of those new techniques/materials for repair/ restoration of the buildings/structures, for long term sustainable development. The author has discussed the various causes of deterioration and the methods for the repair, rehabilitation and retrofitting. The author has also explained various materials and techniques for the repair, rehabilitation and retrofitting and also the methodologies for the same.

Bhavar Dadasaheb O. et al in [3] have discussed the retrofitting of the existing RCC buildings in Gujarat which are located on the boundary of Gujarat-Maharashtra like Nasik, Dhule and Nandoorbar. In his paper the author has taken the case of a health building in the heart of the Nasik city. Based on the physical and experimental investigations it was concluded that the structure either should be demolished or at least should be rehabiliated/retrofitted with appropriate method to enchance the service life of the building.

The RCC columns were strengthed by jacketing technique as this technique was more feasibile and easy to execute at the site. All the columns on both the floors are now properly strengthened by jacketing, the concrete from the faulty slabs are completely removed and the corroded reinforcement is changed with new reinforcement bars as per the design condition. And the slabs are re-casted with M25 grade of ready mix concrete.

S.S. Chandar in [4] has presented the present process of rehabilitation, retrofitting characteristics and technical aspects of the major intervention methods. In addition, selected tests and feasible techniques as per the latest advances in the industry to be used for health assessment, retrofitting and rehabilitation are presented in depth with example calculations.

From literature review, it is clear that RCC building undergo deterioration and subsequent failure due to many reasons. It is therefore proposed to undertake study on RC framed buildings so as to suggest a proper methodology. The building under consideration has been assessed for the causes of deterioration and for the repair, rehabilitation/ strengthening work based on investigation in order to suggest a suitable model for rehabilitation of RCC buildings. The objectives of the study are to suggest a model for systematic approach for the repair work.

RCC building (P-21) located at Udhampur J&K, India was selected to carry out the investigation. The building was around 32-35 years old. Detailed visual inspection was carried out to scrutinize the type, extent and source for damage. An investigation was carried out to check the concrete quality, corrosion in reinforcing bars, carbonation of concrete and ingress of salts in concrete. The concrete quality was found out by using Ultrasonic Pulse Velocity and Hammer Rebound method. The carbonation depth was determined by use of Phenolphthalein test. The plan of building is shown in Figure 1. The detailed investigation plan is shown in flow chart.

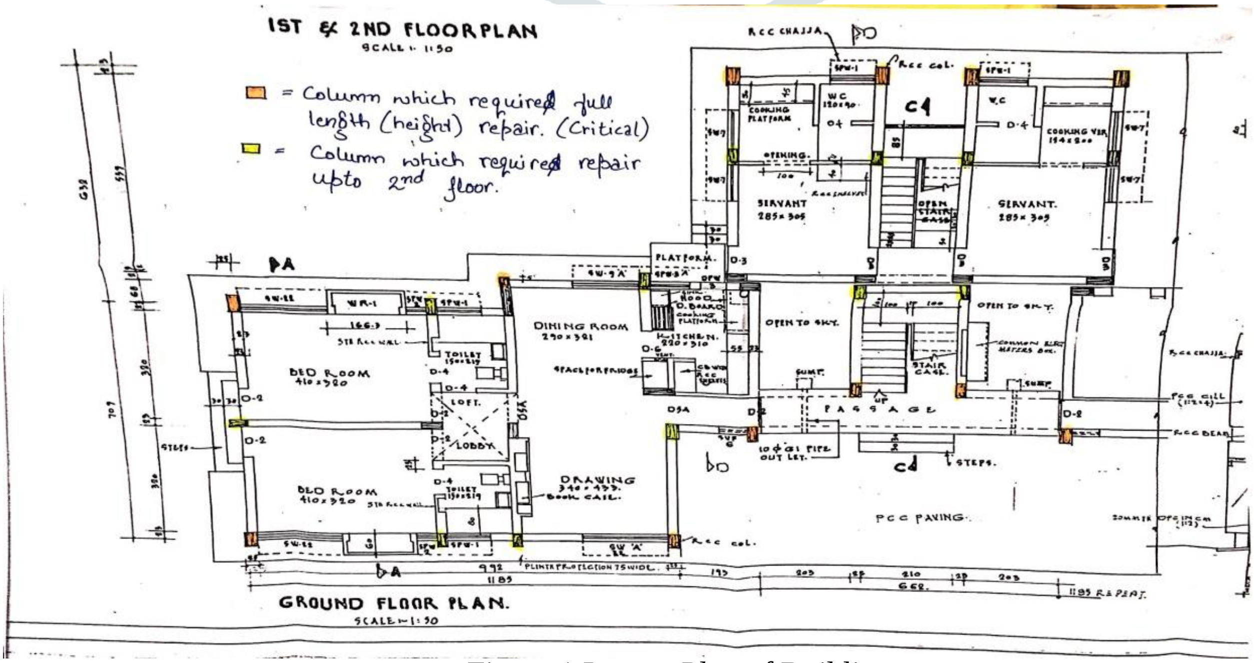


Figure 1 Layout Plan of Building

1.2 OBSERVATIONS

1.2.1 Visual Inspection

a) It was observed that the exterior columns of the building having vertical cracks and spalling at some of the locations.

b) Dampness and efflorescence on walls as also observed specially at the lower level of the building.

c) Some minor cracks along the openings of the windows and doors.

d) Damaged staircase of servant quarter entrance from the backyard of the building.

e) Spalling of concrete and exposed corroded reinforcement in exterior columns of the both the buildings.

f) Termite attack on the ground floor and 1st floor of the building.

g) Backside staircase along with the servant quarter of building is completely damaged.

h) Brick tiles on the terrace of the building are damaged which leads to the ingress of water through them.

i) Plantation growth on the terrace of the building and the rainwater pipes are damaged.

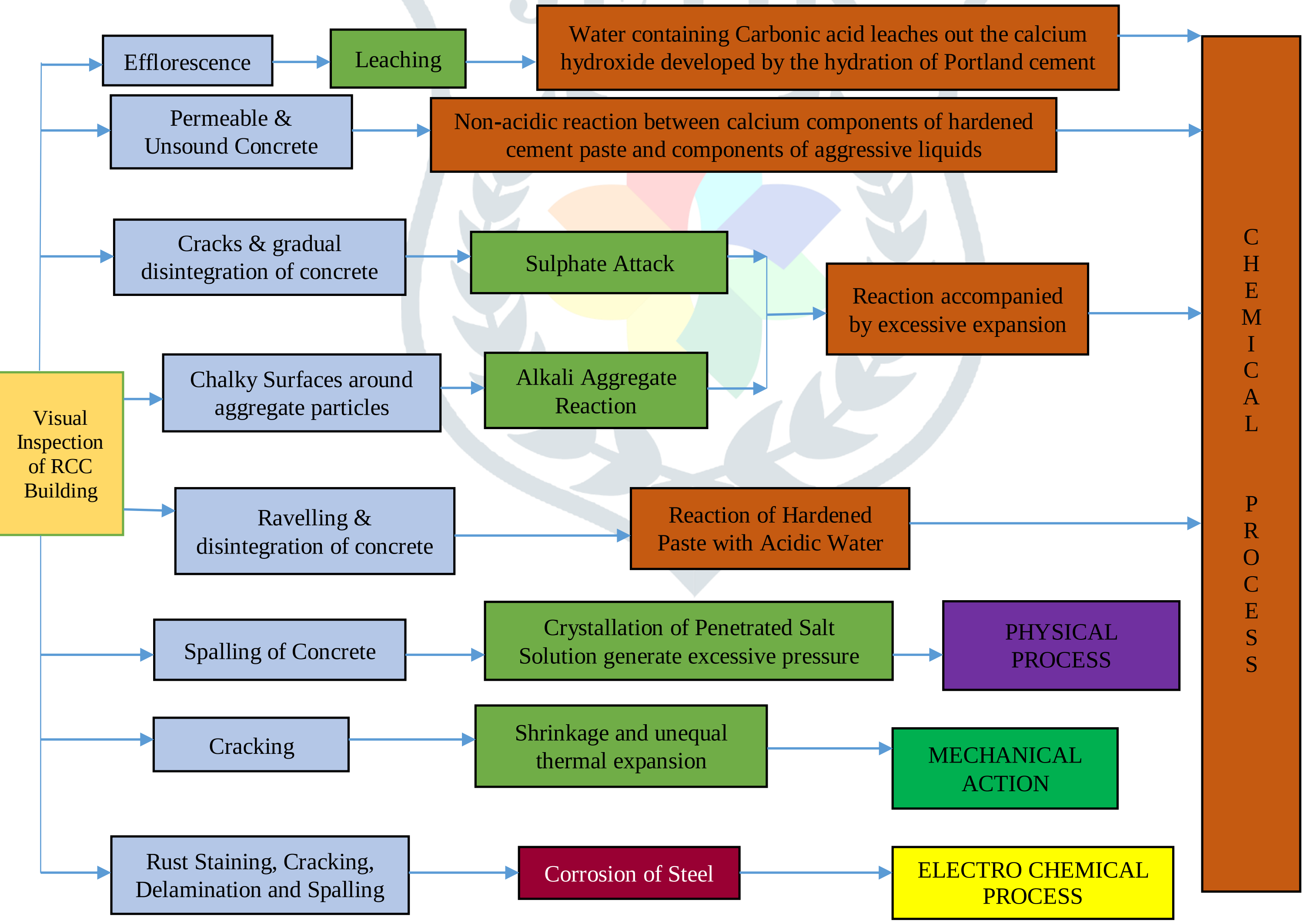


Figure 2: Flow chart

Figure 3 Corrosion in steel

Figure 4 Spalling of Concrete

Figure 5 Hair Line cracks in column

Figure 6 Vertical crack on column

1.2.2 NON- DESTRUCTIVE TESTING OF STRUCTURE

A number of non-destructive and partially destructive techniques for the assessment of the concrete structure and also to predict the cause of deterioration of the existing structure are available. In the overall world the interest of Non-Destructive Testing (NDT) increasing day by day. These NDT techniques can be broadly classified into four groups like Strength tests, Durability tests, Performance tests and Integrity tests and Chemical tests. With the help of these tests we can find out in-situ strength/quality of the concrete to precise identify the damage and causes of the deterioration of the structure. Details of few of the tests, which are commonly used in practice, are described below-

a) **Schmidt Hammer Test**- This is the fastest method to evaluate the quality of concrete based on hardness, which is indicated by rebound number. If the strength of concrete is high, the rebound number is also high. The principal of this test is that when the plunger of rebound is pressed against surface of the concrete the spring controlled mass rebound and the extent of such rebound depends upon the surface hardness of the concrete. The surface hardness of the concrete and therefore the rebound number is taken to be related to the compressive strength of the concrete. In the latest rebound hammer there is need for angle correction.

Table 1 Concrete Cover

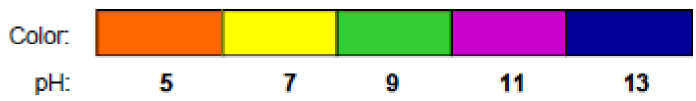
INSTRUMENT	AVERAGE REBOUND NUMBER	QUALITY OF CONCRETE
Schmidt Hammer N-TYPE	Greater than 40	Very good hard layer
	30 to 40	Good layer
	20 to 30	Fair
	Less than 20	Poor concrete
	0	Delaminated

b) Ultrasonic Pulse Velocity Test-Ultrasonic Pulse Velocity Test (UPV) method is generally used for determination of uniformity of concrete, to find crack the depth, honeycombing, and to check the condition assessment of deterioration of concrete. The principal of this test based on propagation of electro acoustic pulse through the concrete pathway and calculating the transit time taken, for a known distance. Ultrasonic Pulse velocity depends mainly on elastic modulus of concrete.

Table 2 General Guidelines for Concrete Quality Based on UPV

VELOCITY (km/sec)	**CONCRETE QUALITY**
Greater than 4.0	Very good to excellent
3.5-4.0	Good to very good slight porosity may exist
3.0 -3.5	Satisfactory but loss of integrity is suspected
3.0	Poor and loss of integrity exists

c) Carbonation Test- Concrete is having micro-pores and these pores are filled with liquid, having pH-values as high as 12.5. Thus, the concrete is alkaline in nature. Carbonation of the concrete is the reaction of $Ca(OH)_2$ with atmospheric CO_2, and its conversion into CaCO3. This reaction decreases the pH value of the pore water to about 8.5. The outer zone of concrete is affected first due to passage of time, carbonation proceeds deeper into the mass as CO_2diffuses inwards from the surface. If the carbonation depth equal to the steel of concrete, then steel prone to corrosion damage. By carbonation test, we measure the carbonation depth of the concrete.

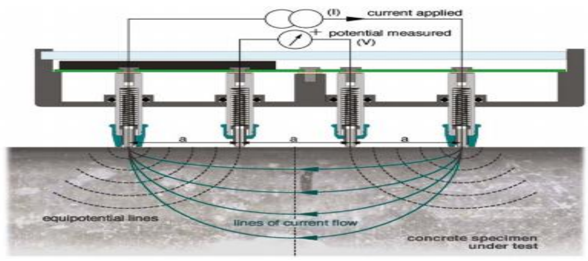


To determine the path of the carbonation drilling of a hole is done in stages and the phenolphthalein solution spread over it after every stage. As soon as the colour of the concrete becomes pink, stop drilling and the depth of the hole measured.

d) Reinforcement Scanning Test- Ferro Scanner is a device used to locate reinforcing bars and estimates the diameter and depth of cover.

This device is based on interactions between the bars and low-frequency electromagnetic fields. The physical principle that is employed is that of electromagnetic induction, whereby and alternating magnetic field induces an electrical potential in an electrical circle intersected by the field. The test for reinforcement scanning is done with help of HILTI PS 200 Ferro scan a portable system for detecting rebar in concrete structures. The tools help in obtaining real image of the reinforcement and evaluate the reinforcement mesh. HILTI PS 200 Ferro scan record the depth and positions of rebars over long stretches and obtain average coverage and statistics. The tools consists of Image Scanner that records the data, then the recorded data is transferred to the monitor for further analysis at the site itself .The major analysis and conclusion is done on the computer on the analysis software to produce reports of the data recorded which is further submitted to the Structural Consultant for Preparation of Structural Drawing and there by establishing the Stability of the Structure. The limitations of this test are interferences may occur in images due to scraps of reinforcement in concrete, tie wires where rebars cross, aggregates with Ferro magnetic properties.

e) **Resistivity Test-** Surface resistivity meter provides very useful information about the surface of the concrete. It is not only provides the corrosion information but also provides the co-relation between the resistivity and chloride diffusion rate. The operating principle of the Wenner probe, the Resipod is designed to measure the electrical resistivity of concrete or rock. A current is applied to the two outer probes, and the potential difference is measured between the two inner probes. The current is carried by ions in the pore liquid. The calculated resistivity depends on the spacing of the probes.



Resistivity ρ= 2πaV/I [kΩcm].

Table 3 Estimation of the likelihood of Corrosion

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

f) **Chloride/Sulphate Ingress Test-** Quantity of chlorides and sulphate in the concrete is generally determined chemically. Sulphate and chloride contents of concrete samples collected from various locations were found out. The permissible limit of chloride contents by weight of cement is 0.4 percent and 0.15 % is enough for the onset of corrosion. Sulphate contents are limited to4.0% by weight of cement.

Table 4 Cover Meter Readings

Sr. No.	TEST RESULTS	INTERPRETATIONS
1.	Required cover thickness and good quality	Not corrosion prone
2.	Required cover thickness and bad quality cover concrete.	Corrosion prone
3.	Very less cover thickness, yet good quality cover concrete.	Corrosion prone

1.3 Results & Discussions:

- From the UPV results, it is observed that all the structural members having very low UPV values. 40.53% elements having the UPV value in the range of 2.5 to 3.0 Km/sec, 33.26% elements having the UPV value in the range of 2.0 to 2.5 Km/sec and 26.21% members' lies in the range of 1.5 to 2.0 Km/sec. The UPV results cannot fulfill the codal requirements.
- The rebound hammer tests shows that compressive strength of members are 35.8%, 29.42%, 19.88% and 14.9% lies in the range of 20 to 25 N/mm^2, 15-20 N/mm^2, 10-15 N/mm^2 and 5-10 N/mm^2 respectively.
- Adequate concrete cover over the reinforcement is one of the crucial parameter, as for as RCC structures are concerned, but the result of percentage distribution of concrete cover reveal that there is great variation in concrete cover. The percentage of less concrete cover is about 54%. This can be one of the reasons of deterioration in concrete and subsequent corrosion in reinforcing bars.
- The pH of external RCC members is decreased to 6-7 and pH of internal members lies in the range of 8-9. From the carbonation depth data it is observed that the depth of carbonation is more. In 45% members the carbonation is reached upto the rebar level. This has been attributed to porous concrete and unprotected external surfaces from weathering actions.
- Concrete resistivity results shows that the members have moderate risk of corrosion.

Observing the damaged condition of the outer columns 12 columns marked in orange color in the plan(fig.1) requires full height repair and 11 columns marked I yellow color in the plan requires repair/jacketing up to second floor. Exposed concrete was found to be carbonated, the carbonated concrete should be provided with anti-carbonation coating if the spalling of cover concrete has not started. Due to the effect of corrosion, the spalling was observed in these columns, so it is necessary to repair the structure so it will be enable to withstand against the combination of loads for which it is designed. The spalling concrete from columns should be repaired with micro-concrete. All the repair work required to be done should be carried out as per the methodology sequence provided above.

Table 5 UPV, RH Values and Carbonation Test Result before repairs

Sr. No	Location	Average Rebound Hammer	Average UPV	Compressive Strength N/mm^2	Compressive Strength After correction of carbonation N/mm^2	Carbonation (pH)
1	C-1	45.3	**2010**	24.5	**22.05**	8-9
2	C-2	43.4	**1541**	22	**19.8**	8-9
3	C-3	26.3	**2073**	10	**9**	8-9
4	C-4	44.7	**1843**	23.5	**21.15**	8-9
5	C-5	47	**2226**	26.5	**23.85**	8-9
6	C-6	41.3	**1773**	20	**14**	6-7
7	C-7	46.6	**2833**	26	**18.2**	6-7
8	C-12	28	**2381**	10.5	**9.45**	8-9
9	C-13	46.2	**2030**	25.5	**17.85**	6-7
10	C-18	44.8	**2551**	24	**21.6**	8-9
11	C-19	40.2	**2212**	19	**17.1**	8-9
12	C-20	30.9	**1895**	12	**10.8**	8-9
13	C-21	31.7	**2368**	14	**12.6**	8-9
14	C-22	36.2	**2128**	15.5	**13.95**	8-9
15	C-23	30.8	**1531**	12	**10.8**	8-9
16	C-24	32	**2579**	13	**11.7**	8-9

Table 6 Test Result of Concrete Resistivity

Sr. No.	Location	Concrete Resistivity test result (Kilo-ohm / cm)
1.	C-1	42,44,38.2,34,36=**38.84**
2.	C-2	18.1,16.4,15.7,15.9,13=**15.82**
3.	C-3	23,27,20.6,20.4=**22.75**
4.	C-4	42,37,36.2,33.1=**37.07**
5.	C-5	42,44,38.2,34,36=**38.84**
6.	C-6	21,22.4,16.8,17.8=**19.5**
7.	C-7	23,27,20.6,20.4=**22.75**
8.	C-12	22,23.4,25.6,28.5=**24.88**
9.	C-13	18.1,16.4,15.7,15.9,13=**15.82**
10.	C-18	34,42,44.3,41=**40.32**
11.	C-19	18,18.5,22.3,22=**20.2**
12.	C-20	**21,22,21.8,23=21.95**
13.	C-21	24,26,20.4,20.6=**22.75**
14.	C-22	45,43.2,42,32.5=**40.67**
15.	C-23	11.4,16.2,14.3,13.9=**13.95**
16.	C-24	28,36,31.8,34.2=**32.5**

Table 7: Sulphate/Chlorides Ingress

Sr. No.	Location	Chlorides	Sulphates
		By weight of cement (%)	By weight of cement (%)
1.	C-19	0.39	3.6
2.	C-2	0.41	3.2
3.	C-22	0.36	2.9
4.	C-4	4.1	3.2
5.	C-7	4.2	3.15
6.	C-21	0.39	3.3

Table 8 UPV & RH Results after repair

Sr. No.	Location	Average Rebound Hammer	Average UPV	Compressive Strength N/mm^2
1	C-1	50.6	**4025**	31.42
2	C-2	48.2	**3643**	28.00
3	C-3	47.8	**3573**	27.47
4	C-4	50.4	**3844**	31.13
5	C-5	51.4	**3926**	32.60
6	C-6	49.2	**3763**	29.40
7	C-7	48.8	**3683**	28.80
8	C-12	50.5	**4088**	31.27
9	C-13	47.9	**3830**	27.60
10	C-18	52.1	**4121**	33.78
11	C-19	50.4	**4025**	31.13
12	C-20	49.5	**3735**	29.81
13	C-21	50.3	**3895**	30.98
14	C-22	51	**4025**	32.00
15	C-23	48.7	**3876**	28.68
16	C-24	47.8	**3680**	27.47

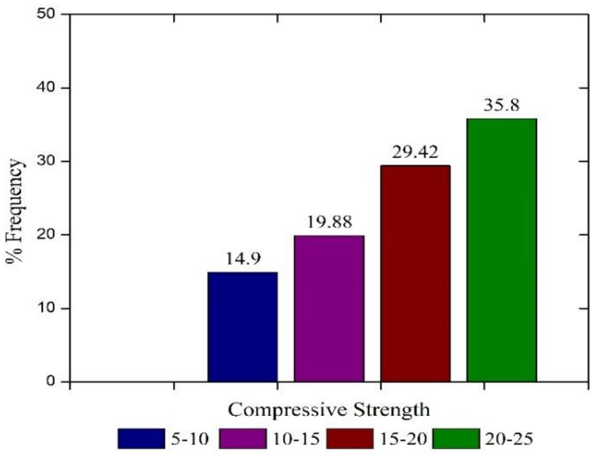
1.4 SUMMARY OF PROBLEMS AND DEFECTS

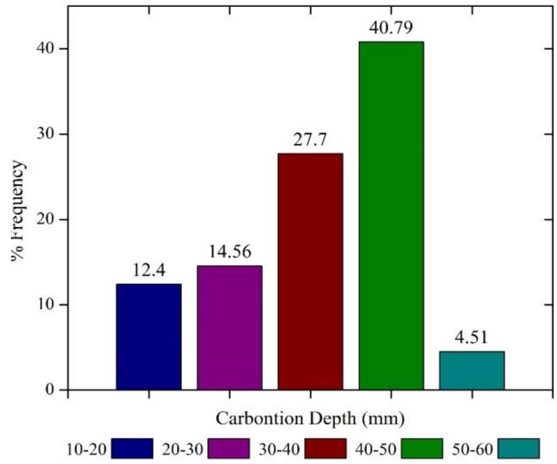
1. Cracks: Major throughout cracks was observed at few locations in outer columns of the buildings. Minor cracks near openings of windows and doors in most of the locations. Cracks were also observed on parapet of terrace.
2. Rusting of bars: The corrosion was observed at few locations due to spalling of concrete or carbonation of concrete.
3. Spalling of concrete: spalling of concrete is observed in outer columns of the buildings.

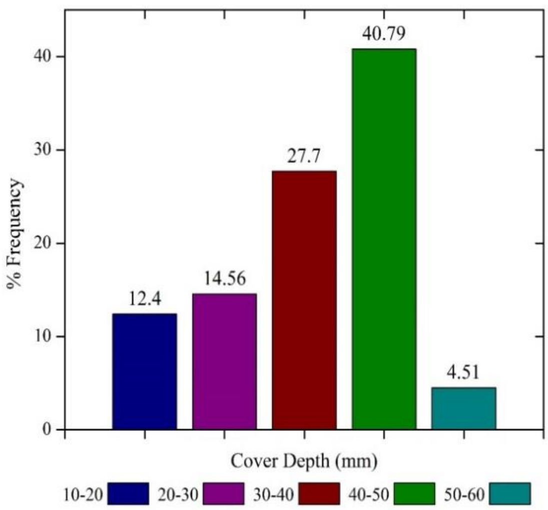
4. Dampness & Efflorescence: Dampness and efflorescence have been observed in most of the houses especially at ground level, near sunken area & near staircase areas.

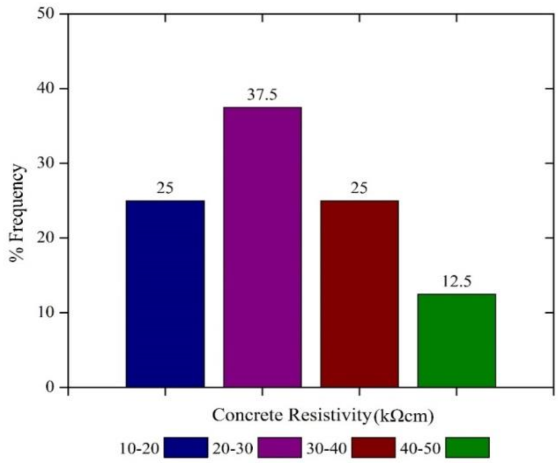
5. Railing: The present railing is damaged and need to be replaced.

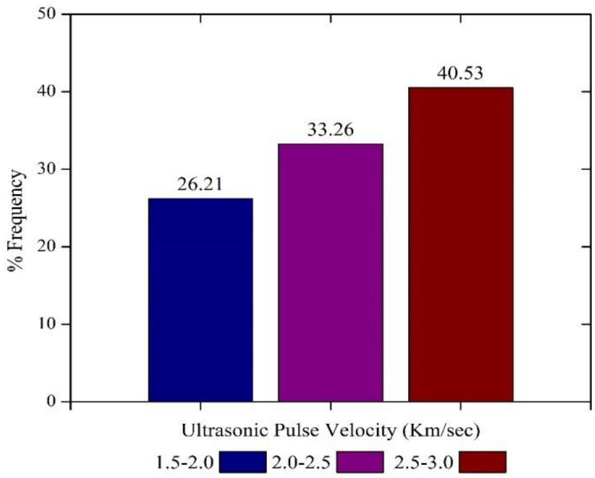
The NDT carried out after repair showed that the concrete strength was in the range of M25 to M30 grade of concrete. The ultrasonic pulse velocity also showed the quality of concrete improved from poor to good. The fig no- & fig no- shows that after repairs the strength and quality has got enhanced which will also result in improvement of durability of structures in the long run.

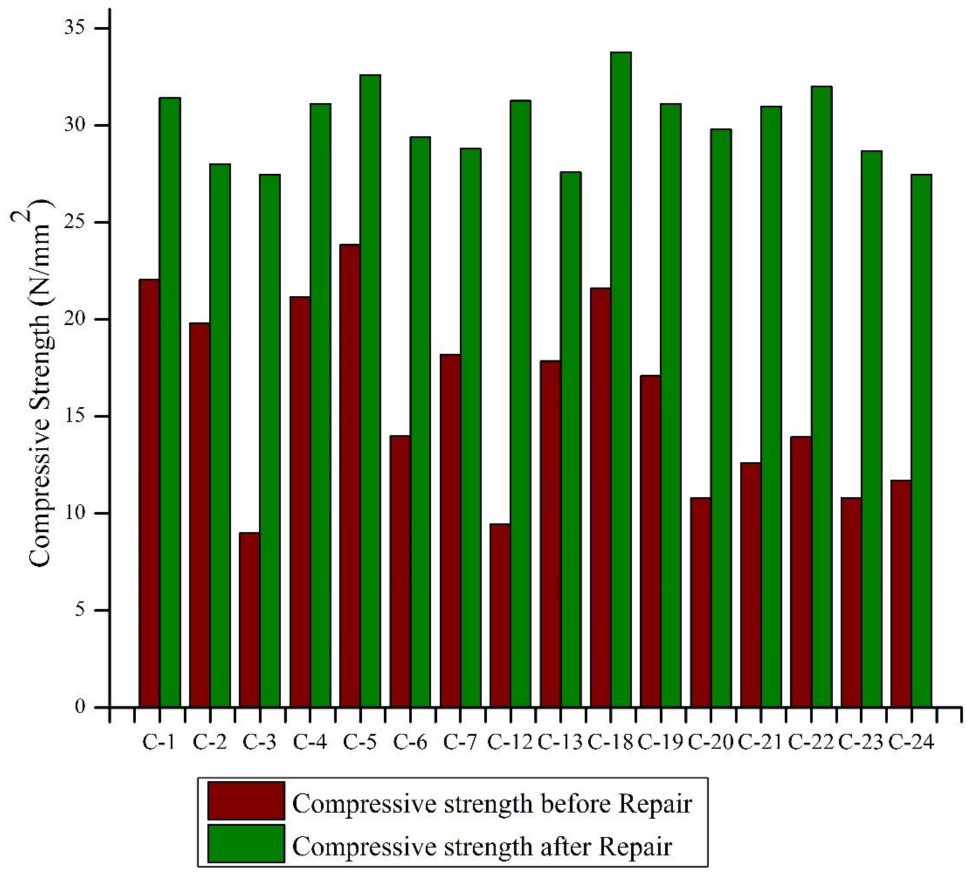


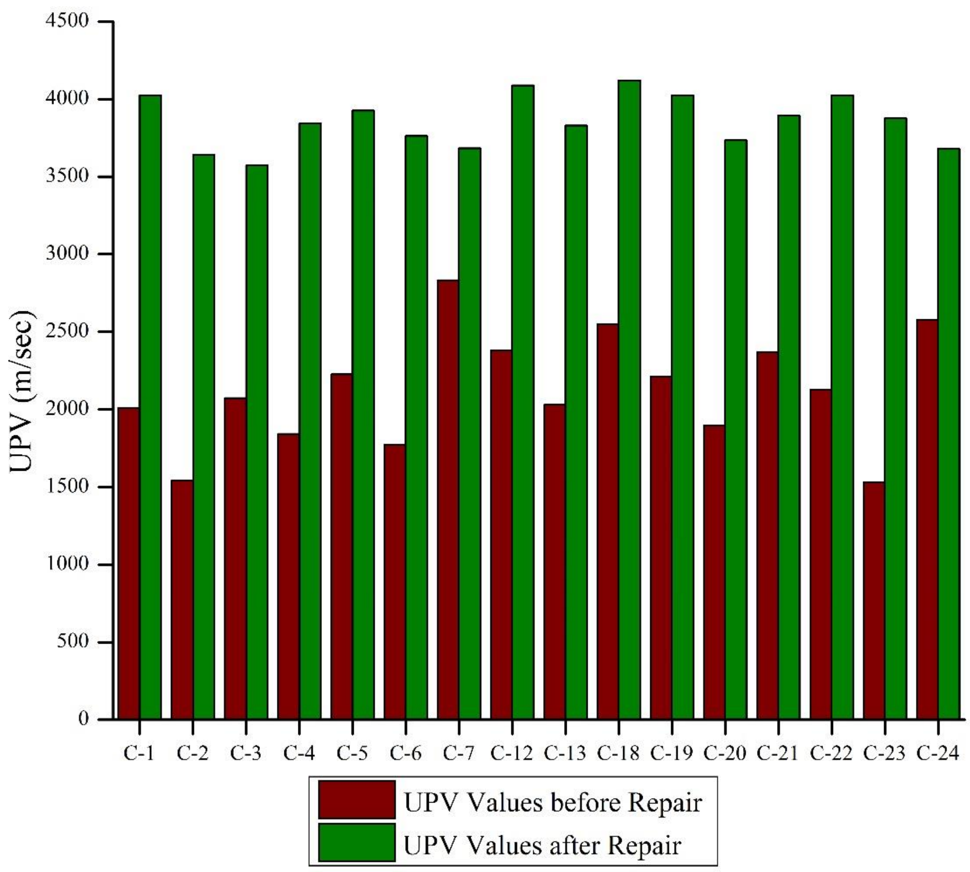









Compressive Strength (N/mm^2)
35
30
25
20
15
10
5
0
C-1 C-2 C-3 C-4 C-5 C-6 C-7 C-12 C-13 C-18 C-19 C-20 C-21 C-22 C-23 C-24
Compressive strength before Repair
Compressive strength after Repair


UPV (m/sec)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
C-1 C-2 C-3 C-4 C-5 C-6 C-7 C-12 C-13 C-18 C-19 C-20 C-21 C-22 C-23 C-24
UPV Values before Repair
UPV Values after Repair

1.5 Repair methodology

- The strengthening of Outer columns of the building is to be done with jacketing with micro concrete reinforcement is to be provided where steel is rusted more than 20%.
- All the traps and manholes should be repaired to prevent the seepage into the foundations from such locations.
- Water tanks on the roof are causing dampness due to the overflow of water or due to leakage, all the tanks should be repaired and overflow should be stopped by providing suitable float valve.
- Exposed concrete was found to be carbonated, the carbonated concrete should be provided with anti-carbonation coating if the spalling of cover concrete has not started.
- If the spalling of cover concrete is taking place the same should be repaired by treating the affected reinforcement and repairing the cover with micro concrete.

The suggested model for carrying out repairs of structures and their strengthening is shown in the flow diagram.

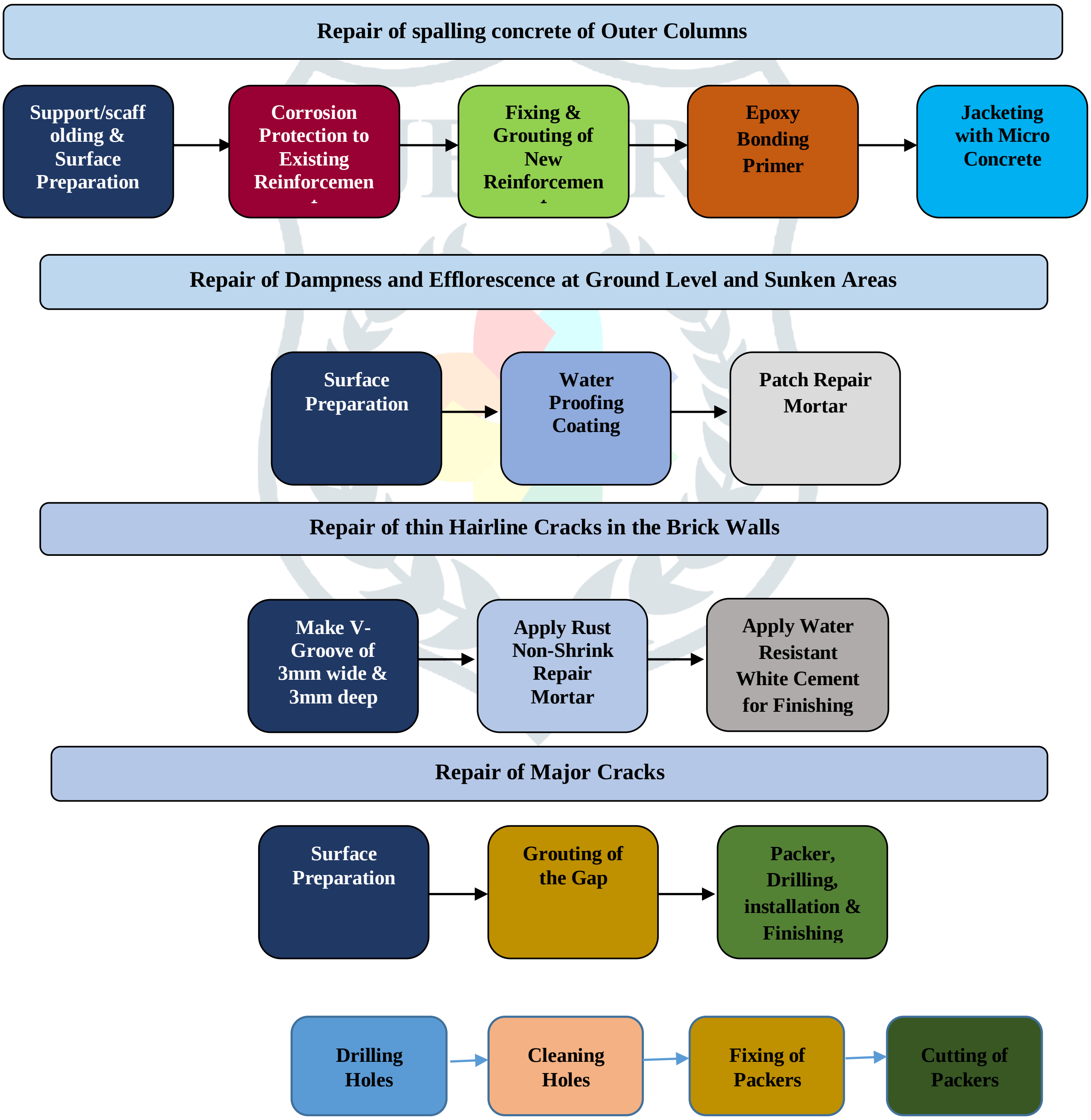


Figure 7 Suggested flow diagram for repair & strengthening

1.6 Conclusion:

Based on the investigations following conclusions are drawn

- Rebound hammer and UPV tests give the reasonable assessment of in-situ strength of RCC members.
- Deterioration of external exposed concrete members due to carbonation is high as compare to internal members.
- Adequate concrete cover to reinforcement is one of the important parameters for RCC Structures. Major reason of spalling and corrosion in reinforcing bars is due to inadequate concrete cover. The porosity of concrete and unprotected external surfaces results in high rate of carbonation.
- A systematic approach to repair and rehabilitation is to be adopted after carrying out the proper monitoring with the help of non-destructive testing techniques.
- The monitoring to check the effectiveness of strengthen structures can be checked by NDT Technique.

REFERENCES

1. IS 456-2000, Plain and reinforced concrete-code of practice, *Bureau of Indian Standards, New Delhi*.
2. Advances in Repair and Rehabilitation of concrete structure AR^{2}CS-2016.
3. S.K. Singh and S.K. Kirthika, "Review on various non-destructive testing methods for assessment of buildings".
4. N. Subramanian & K. Geetha,(2012), "Concrete Cover for Durable RC structures", *Indian Concrete Journal.*
5. Sanjay Sharma, "NDT Methods for assessment of quality of RCC structures", *Advances in Repair and Rehabilitation of concrete structure AR^{2}CS-2016.*
6. B. Singh, Hina Tarranum and Richa Singh, "Advances in Repair material for Strengthening of Deteriorated building Structures".
7. Peter P.S. (1987), "Corrosion Damaged Concrete Assessment and Repair" *Butterworths, London.*
8. CPWD handbook on Repairs and Rehabilitation of RCC Buildings, *Published by Central Public Departments (CPWD),* Government of India.
9. National Building Code (2005), published by *Bureau of Indian Standards, New Delhi*
10. ACI 562-13, (2014), "Code requirements for Evaluation, Repair and Rehabilitation of Concrete building", *American Concrete institute.*
11. Lakshmy Parameswaran, "Distress Diagnostics of Concrete Bridges" *Advances in Repair and Rehabilitation of concrete structure AR^{2}CS-2016.*
12. Rama Raju M.V. and D.S Prakash Rao, In-situ Investigation on Construction Practices, *International Conference on Rehabilitation, Renovation and Repair of structures,* Andhra University, Visakhapatnam.
13. Singh. V.V, 2005, "Selection of Polymers for Repair and Rehabilitation of RC Structures, Point of view", *Indian Concrete Journal*.
14. McCann, D.M. and Forde, M.C.(2004). "Review of NDT methods in the assessment of concrete & masonry structure". NDT & E-international.34(2001).71-84
15. IS: 1311, Part 1 & 2, Non-Destructive Testing of Concrete Methods of Test, *Bureau of Indian Standards, New Delhi (1996).*

Author's Profile

1* Er. Aman Kumar

2* Er. Navdeep Mor