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Non-Destructive Testing of Composite Materials

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Abstract:
Composite materials, these days have become an integral part of any construction. In India infrastructure industry is growing rapidly due to globalization, raising awareness and growing importance of India around the globe. Most of the structures, these days, are built using composite materials. Despite improved properties of the materials they are still facing the common structural problems which consist of cracks, spalling, corrosion, leakage, chloride & sulphate attack, carbonation etc. If these problems are not solved at their initial stages then it might lead to the serious damages to the structures. This paper deals with non-destructive analysis of residential building composed of the composite materials such as reinforced cement concrete wherein the building has been assessed using rebound hammer test, ultrasonic pulse velocity test, carbonation test and resistivity test in concrete. 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 the deterioration of the materials used in building. The test results have shown a significant decline in the strength and the durability properties of the materials used in the building.

Keywords: *Composite Materials, Rebound Hammer Test, Ultrasonic Pulse Velocity Test, Carbonation.*

1. INTRODUCTION

Despite possessing high resistance to the environmental deterioration, concrete as construction material at various occasions, shows indications of damage (Adesina et al., 2019; Chindaprasirt et al., 2019; Vaidevi et al., 2019). A number of deteriorating agencies make the R.C.C structure structurally deficient (Kissman et al., 2019). There are various test methods available for evaluating the health of the reinforced concrete structures without destroying it (Sandeep Kumar et al., 2018; Sanjay Kumar et al., 2013). These non-destructive techniques can be broadly classified into four groups i.e. strength tests, durability tests, performance tests, integrity tests and chemical tests (Sanchez et al., 2014; Shariati et al., 2011). With the help of these tests we can find out in-situ strength/quality of the concrete to precisely identify the damage and causes of the deterioration of the structure (Breysse, 2012; Pucinotti, 2015; Shukla et al., 2020; Villain et al., 2012). Ultrasonic pulse velocity test serves as a means to check the homogeneity and the integrity of the concrete (Jadon et al., 2019; Sairam et al., 2019; Singh et al., 2017). Rebound hammer test along with the carbonation test helps in estimating the compressive strength of the cover concrete (Chang et al., 2006; D.W.S. Ho and R.K. Lewis, 1987). Most of the structures, these days, are built using composite materials due to its high corrosion resistance and damage sensing properties [Kumar et al. 2020, Kumar et al. 2019, Kumar et al. 2020]. Electrical resistivity measurement techniques are finding its relevance among researchers for the assessment of the durability of concrete. The concrete can be evaluated for its performance using electrical resistivity method which is much easier than RCPT (Hamed Layssi, Pouria Ghods, Aali R. Alizadeh et al., 2015). In Nernst-Einstein equation, the value of the resistivity finds its direct relation to the chloride diffusion coefficient of concrete (Lu, 1997). Many mechanisms and phenomenon are responsible for the concrete deterioration but the most prominent is the corrosion of reinforcement which drastically damages the strength and the durability of concrete structures (Al-saleh, 2015, Shukla et al. 2019). Chloride ions in concrete set up a major source of durability issues distressing reinforced concrete that is exposed to environment. When enough amounts of chloride ions gets accumulated around the reinforced steel, a localized corrosion in which small holes and cavities starts developing, is liable to occur unless the environmental surroundings are intensely anaerobic (Carmen Andrade et al., 2002). A number of studies have targeted the sulphate ion ingress as one of the reason for the reduced durability of the reinforced concrete structures (Condor et al., 2011; Santhanam et al., 2002; Zhou et al., 2015). In this paper 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, and carbonation of concrete and ingress of salts in concrete. A total of 16 reinforced columns at different locations were tested using non-destructive testing and 6 columns were also tested for the presence of the chlorides and sulphate in the concrete.

2. TESTS AND METHODS

2.1 Ultrasonic Pulse Velocity Test

This test is conducted in accordance with IS 516 (Part5/Sec1): 2018(BIS, 2018). The apparatus used is TICO of Proceq Testing Instruments with 54 kHz transducers. Ultrasonic Pulse velocity depends mainly on elastic modulus of concrete. Table 1 below describes the criteria as per IS code.

Table1. UPV Criteria for Assessing the Quality of Concrete

S. N	Average UPV Value(km/s)	Quality of Concrete
1	> 4.40	Excellent
2	Between 3.75 and 4.40	Good
3	Between 3.0 and 3.75	Doubtful
4	< 3.0	Poor

2.2 Rebound Hammer Test

This test is conducted as per the specifications given in IS 13311-2:1992(Kisan et al., 1992). Schmidt N-type hammer is used in the present study. More is the strength, higher is the rebound number. The surface hardness of the concrete and hence the rebound number may be considered as a measure of the strength of the concrete. Table 2 below mentions the criteria as per IS code.

Table2. Rebound Number Criteria for Concrete Quality

S. N	Instrument	Avg. Rebound Number	Concrete Quality
1	Schmidt Hammer N-TYPE	More than 40	Excellent
2		Between 30 and 40	Good
3		Between 20 and 30	Fair
4		Less than 20	Poor
5		0	Delaminated

2.3 Carbonation Test

Rainbow indicator is used for the estimation of the extent and depth of carbonation. Carbonation of the concrete reduces the pH value of the water present in the pores of the concrete to about 8.5. Embedded steel reinforcement will become prone to corrosion once the depth of carbonation reaches the depth of reinforcement.

2.4 Resistivity Test

The Resipod resistivity meter (Proceq SA, 2017), which works on the principle of Wenner probe, was used for measuring the resistivity of concrete (Gupta et al. 2020). The meter consists of two outer probes through which the current is applied and the

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potential difference is recorded b/w the two inner probes. Values of the resistivity can be interpreted from Table 3 below.

Table3. Estimation of the Likelihood of Corrosion

S.N	Resistively level (Kilo-ohm/cm)	Possible Corrosion rate
1	≥ 100 kΩ	Negligible
2	Between 50 and 100	Low
3	Between 10 and 50	Moderate
4	≤ 10	High
5	Resistively level (Kilo-ohm / cm)	Possible Corrosion rate

3. RESULTS & DISCUSSIONS

3.1 UPV, Rebound Hammer and Carbonation Test

Figure 1, 2 and 3 below represents the data of the non-destructive tests that were conducted on a total of 16 columns. At each column, a total of 3 readings for UPV and 9 readings for rebound number were taken to arrive at their average values. A core has been taken from each column and the depth and extent of carbonation is determined by spraying the rainbow indicator over the sample.The results have shown the variation of ultrasonic pulse velocity from as low as 1.53 km/s to a maximum of 2.83 km/s. The rebound numbers varied from 26 to 47 and the carbonation values are in the range of 6-9. These low values of ultrasonic pulse velocities indicate the porosity and loss of integrity of the concrete (Kim et al., 2009). The low values of rebound numbers are also indicating the loss of strength of cover concrete. These rebound number values are too because of the carbonation of the cover concrete which tend to increase the rebound number values (Breccolotti et al., 2013).Major throughout cracks were observed at a few locations in outer columns of the building which is clearly reflected in the low UPV values at those locations. Minor cracks near openings of windows and doors in most of the locations, cracks on parapet of terrace were observed.

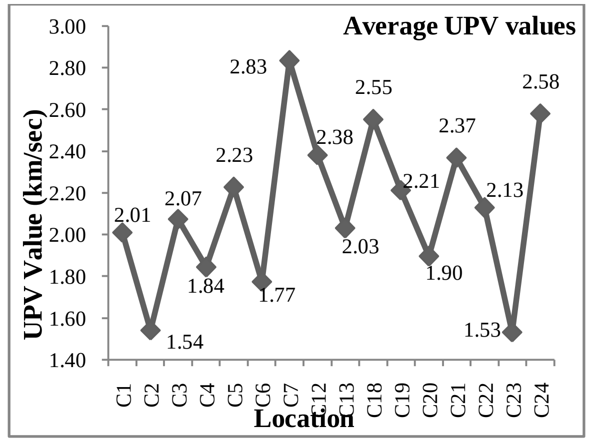

Figure1. UPV Values

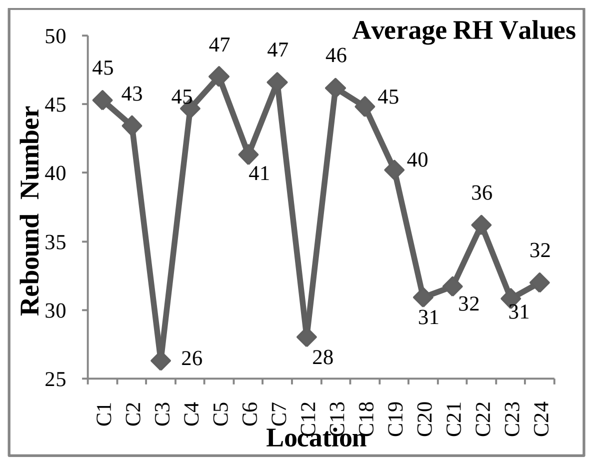

Figure2. Rebound Hammer Values

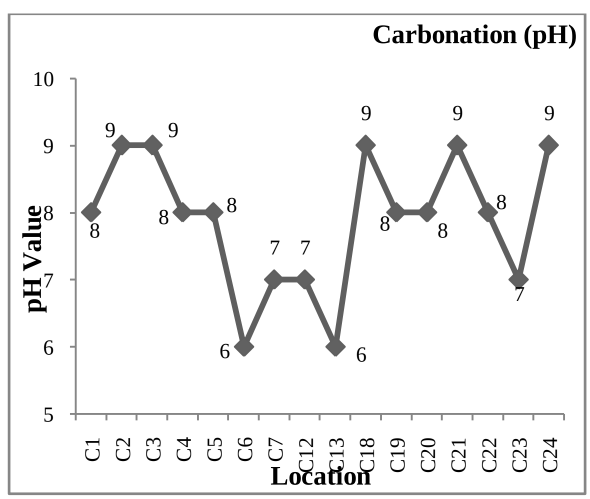

Figure3. pH Values

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On analyzing the values of ultrasonic pulse velocities and the rebound numbers, the compressive strength of the composite material i.e. reinforced cement concrete was found to be lying in the range of 10MPa - 26.5MPa. When the correction of carbonation is applied to the determined compressive strength values, it further dropped to a value of 9MPa from 10MPa and to a value of 23.9MPa from 26.5 MPa. The detailed analysis can be clearly seen in the Figure 4 below. Exposed concrete was found to be carbonated. The carbonated concrete should be provided with anti-carbonation coating(Lo et al., 2016; Sanjuã, 2001) 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

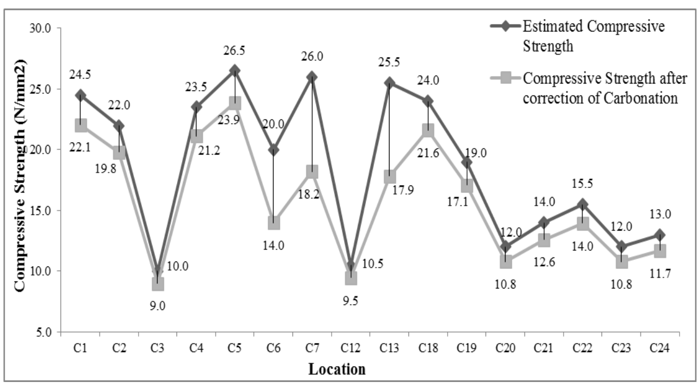

Figure4. Estimated and Corrected Compressive Strength

3.2 Concrete Resistivity

From figure 5 below, it can be seen that the resistivity values of the reinforced cement concrete as determined using Resipod resistivity meter was found to be varying from 13.95 kΩ/cm to 40.67 kΩ /cm. These low values of the resistivity are an indication of moderate to high rate of corrosion in the embedded steel reinforcement [29].

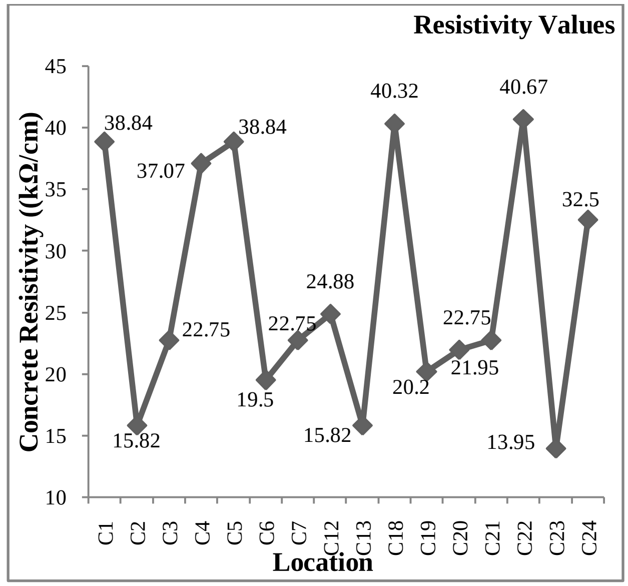

Figure5. Resistivity Values

The corrosion was observed at a few locations due to spalling of concrete or carbonation of concrete. Spalling of concrete is observed in some of the locations such as outer columns of the buildings. Dampness and efflorescence have been observed in areas especially at ground level, near sunken area & near staircase areas.The strengthening of outer columns of the building is to be done using jacketing with micro-concrete reinforcement(Raval et al., 2013; Sakino et al., 1985). This treatment has 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.

4. CONCLUSIONS

The composite material used in the building construction despitehaving high resistanceagainstenvironmentaldeterioration, also undergo a negative impact on its characteristic properties. Observing the damaged condition of the material in the outercolumns of the building, it can be concluded that these columnsmayrequire full heightrepair and almost all the columns also requirejacketing up to second floor. Exposed concrete was found to be carbonated. The carbonated concrete should be provided with anti-carbonationcoatingif 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 sothat it can resist the combination of loads for which it is designed. The spalling concrete from columnsshould be repaired with micro-concrete.

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