Condition assessment of the structural elements of a reinforced concrete structure using non-destructive techniques

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Abstract. Assessment of the strength and durability properties of structural elements of a reinforced concrete structure can be of great importance for either tracing potential damaged areas or for carrying out the reliability analysis. Composite materials, these days have become an integral part of any construction. Most of the structures are built using concrete as the construction material. Inspite of the strong and durable nature of the concrete as a material, the RCC structures still face common structural issues that includes cracking, spalling, rusting of reinforcement, dampness, acid attack, carbonation etc. If these issues are left unattended during the initial stages then they may cause serious distress in the structures. This paper reports the condition assessment of the structural elements of a residential building using non-destructive techniques. The hardness and the strength of the cover concrete has been assessed using rebound hammer test, structural integrity and homogeneity by ultrasonic pulse velocity test. Additionally, carbonation test and resistivity test were also conducted to assess the extent of corrosion. The results of the assessment have shown a noteworthy decay in the strength and the durability properties of the structural elements.

Keywords: Concrete structures, condition assessment, Non-destructive testing, Rebound hammer, Ultrasonic Pulse Velocity, Carbonation.

1. Introduction

Inspite of having great resistance to the surrounding environmental deterioration, concrete as construction material shows significant signs of distress [1–3]. Various deteriorating agents such as acids, salts, chlorides, sulphates in water and carbon dioxide make the reinforced concrete structures structurally deficient [4–8]. A number of techniques are available for assessing the condition of the reinforced concrete structures without actually damaging them [9,10]. These non-destructive and semi-destructive techniques include strength tests, durability tests, performance tests, integrity tests and chemical tests [11,12]. The in-situ strength and quality of the concrete can be determined using these NDT methods to precisely detect the distress and causes of the distress to the structure [13–15]. Ultrasonic pulse velocity test determines the homogeneity and the integrity of the concrete [16–18]. Rebound hammer test along with the carbonation test helps in assessing the compressive strength of the cover concrete [19,20]. 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 [21]. In Nernst-Einstein equation, the value of the resistivity finds its direct relation to the chloride diffusion coefficient of concrete [22]. 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 [23].
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 [24]. The loss of strength of reinforcing steel due to corrosion, bond slip etc. makes the structure unsafe during the earthquake forces. A number of research works focused on improving the bond between the reinforcing bars and concrete [25–28]. A number of studies have targeted the sulphate ion ingress as one of the reason for the reduced durability of the reinforced concrete structures [29–31]. In order to reduce the cement content and to improve the durability of the concrete structures different types of industrial and agricultural waste based pozzolans have been utilized [32–35].

This paper presents the condition assessment of a multi-storeyed residential building. The assessment has been done by first visually inspecting the entire building to scrutinize the type, extent and source of damage and to locate the test points. And then the non-destructive investigation was carried out to check the concrete quality, corrosion in reinforcing bars, carbonation of concrete and ingress of salts in concrete. A total of 16 reinforced concrete columns at different locations were tested using non-destructive testing and 6 columns were 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 [36]. The quality of the structural elements that indicate the level of workmanship such as uniformity, presence or absence of internal flaws, cracks and segregation, etc., can be easily assessed using this test. 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 stipulated in IS 516 (Part5/Sec1): 2018.

| 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 [37]. Schmidt N-type hammer is used in the present study. As a general guideline higher is the rebound number, the more is the strength of the cover concrete. The surface hardness of the concrete and hence the rebound number may be considered as a measure of the strength of the concrete. A number of factors such cement type, aggregate type, moisture, age of structure and the degree of carbonation influence the rebound number. Table 2 below mentions the criteria as stipulated in IS 13311-2:1992.

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

2.3 Carbonation Test
This test is conducted to determine the extent of corrosion in the reinforcement by measuring the pH of the concrete. In this study, rainbow indicator was 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 [38], which works on the principle of Wenner probe, was used for measuring the resistivity of concrete. The meter consists of two outer probes through which the current is applied and the potential difference is recorded b/w the two inner probes. Values of the resistivity can be interpreted from Table 3 below.

| 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                    |

3. Results & Discussions

3.1 UPV, Rebound Hammer and Carbonation Test

All the testing were performed 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 extracted cores. Figure 1, 2 and 3 represents the results of the ultrasonic pulse velocity, rebound hammer and pH values respectively.
The results have shown the variation of ultrasonic pulse velocity from as low as 1.49 km/s to a maximum of 2.91 km/s. The rebound numbers varied from 24 to 48 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 [39]. 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 [40]. 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. On analysing 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 11.5 MPa - 26.7 MPa. When the correction of carbonation is applied to the determined compressive strength values, it further dropped to a value of 10.5 MPa from 11.5 MPa and to a value of 23.1 MPa from 26.7 MPa. The detailed analysis can be clearly seen in the Figure 4.

Exposed concrete was found to be carbonated. The carbonated concrete should be provided with anti-carbonation coating [41,42] 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.

3.2 Concrete Resistivity

The testing was done on all the selected 16 columns using Resipod resistivity meter that works on the principle of Wenner probe. The potential difference that occurs between the inner probes was measured after applying a current in the outer probes.
From Figure 5, 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 14.12 kΩ/cm to 39.77 kΩ/cm. These low values of the resistivity are an indication of moderate to high rate of corrosion in the embedded steel reinforcement [43].

4. Conclusions

The composite material used in the building construction despite having high resistance against environmental deterioration, also undergo a negative impact on its characteristic properties. Observing the damaged condition of the material in the outer columns of the building, it can be concluded that these columns may require full height repair and almost all the columns also require 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 that it can resist the combination of loads for which it is designed. The spalling concrete from columns should be repaired with micro-concrete.

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