Structural health assessment of reinforced concrete structure

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Abstract. There is a magnificent rise in repair, retrofitting and rehabilitation in construction industry in recent years. Concrete is a major used material in construction for various structures mainly because it deteriorates at a low rate. Concrete alone is durable but for structural application, Reinforced concrete is used. Reinforced concrete structures are not that durable because of number of reasons such as variation in construction methods, loading condition in service life and subsequent attack by environmental factors. The external symptoms range from cracking to spalling of concrete. In maximum field cases the main cause of deterioration are penetration of water and aggressive chemicals attack. Carbonation, Chloride ingress, leaching, sulphate attack, alkali-silica reaction are known responsible causes. Due to these reasons, during service life the structure deteriorates, and hence monitoring is required. If the condition of structure is below acceptable limit considering various parameters considered, the structure requires repair and retrofitting. For the study, we have considered G+3 Storey commercial building with a basement. Non-Destructive and Chemical Test. The Rebound hammer, Ultrasonic Pulse Velocity Test, Cover Meter Test, pH Test, Carbonation Test and Chloride Content Test are carried out to understand and analyze the current condition of the structure. The result computed from field and lab test were used as parameters for analyzing the structure in STAAD PRO Software. After assessing, the strengthening scheme for reinforced concrete structural components such as beams, columns and slab is discussed and suggested to increases the service life of structure.

Keyword: Reinforced concrete structure, Non-destructive test, STAAD-Pro, Reinforcement Jacketing.

1. Introduction

Concrete is used around world for the construction of buildings, structures, or any other project. However, with time, the structure starts getting older and shows signs like cracking, splitting, delaminating, pop-out and corrosion of steel. This results in the shortening of life and strength of structure. The designed life of RCC Structure is 50 years, but we know in practicality the life remains elusive. Tearing down the existing structure and retrofitting concrete structures is a critical element to financial success also it is opposed to the green building concept where we want to save energy for the future generation.

Concrete structures built 30–40 years ago do not adapt with present modern code requirement for serviceability and durability. For example, the present-day reinforced concrete codes states that minimum cover for structure built in the extreme condition is 75 mm, whereas during that time the corresponding minimum concrete cover was 50 mm[1]. Furthermore, the theoretical foundation of penetration of chloride in concrete structures was not fully known and well understood. Due to this, lack of understanding of concrete deterioration mechanism, it led to no intended faulty concrete practices.
Therefore, the structure built during that period often have durability problems before its service design life has completed.

The knowledge of health examination of the building called as structural Audit, among civil engineers, residents, and owners of the building is important. It is stated, if the life of structure is greater than 30 years and the structure shows sign of deterioration it needs to be inspected [2]. This periodical structural auditing and diagnosis for health assessment are important for determining the structure's present serviceability and structural life. The structural audit is carried out by non-destructive tests as per code provisions. The success of repairs and restoration is always based on knowledge, analysis, in-depth studies of problems faced in building, proper repair practices, and finally socio-economic considerations.

To repair, the exact reason of distress, types of distress, and correct method of repair of concrete structure is required. The major finding of the author [3], is that to protect our structure, we need to have maintenance frequency and correct material to be chosen for repair. Also, good workmanship during repairing work is necessary for quality repair work. We must have inspection and maintenance at the required interval for all concrete structures. Reliability and Durability of structures can be ensured if all care is ensured.

2. Case study.

This paper presents a health assessment of a commercial reinforced concrete building at Gokul Peth, Nagpur, Maharashtra. The study comprises field test and lab test, followed by analysis and strengthening of structure. The G+3 Storey commercial building with basement is 40- to 50-year-old has plinth area 1620 square meter and a total built-up area of 8100 square meters. The structure comprises 227 shops, including Godowns and restaurant on the ground floor and offices, cubicles, halls of various firms on upper floors.

![Figure 1. Waterlogging in basement](image1)

![Figure 2. Exposed reinforcement.](image2)

![Figure 3. Spalling and seepage.](image3)

The columns are deteriorating due to waterlogging problem in the building and the rainwater is saturated in the basement as shown in figure 1. The slab of the building is damaged because of seepage and corrosion. At some locations, the reinforcement of structure is open and corroded (figure 2 and 3), growth of vegetation is detectable. All this may cause structural failure. The purpose of this study is as follows:

2.1 Determine present condition of Commercial Building.
2.2 Proposing strengthening Scheme.
3. Methodology

For health monitoring and proposing strengthening scheme of structure, the current condition of the structure needs to be investigated.

- Collect built-up drawings and changes occurred during the service period.
- Determine current concrete density, compressive strength, and Modulus of elasticity, Using the following test method.
  1. Rebound Hammer Test.
  2. Ultrasonic Pulse Velocity Test.
- Determine carbonation depth using the Phenolphthalein test.
- Determine Concrete Cover using cover meter test.
- Determine the probability of corrosion of reinforcement bar by using the following test:
  1. Half-cell potential measurement.
  2. pH Test
- Structural drawing and load modelling of a commercial building using STAAD pro. Software.
- Strengthening of structure.

3.1. Present Model

Information on the compressive concrete strength of the structure, plan, location and column, beam and slab details etc., were determined from the available built-up drawing and document specification. The specified concrete strength was 15 N/mm² and water cement ratio as 0.4.

3.1.1 Ultrasonic Pulse Velocity test.

The UPV test (figure 4) was performed as per IS 516 [4], with maximum reading between 1.26 Km/Sec to 4.40 Km/Sec. The quality of concrete was poor and doubtful at maximum locations and good at few locations. As per IS 516, the Ultrasonic Pulse Velocity value with indirect method gives less reading than direct methods generally by 0.5 km/sec and readings mentioned are factored. The compressive strength was determined, firstly using the relationship between ultrasonic pulse velocity and modulus of elasticity as stated in equation 1 [4]. The modulus of elasticity value is then used to determine the compressive strength of concrete as per equation 2[5].

\[
E = \frac{\rho \times (1+u) \times (1-2u)}{1-u} \times v^2
\]  

\[
E = 5000 \sqrt{f_{ck}}
\]

In equation (1) and equation (2), \(\rho\) = Density, \(v\) = Ultrasonic pulse Velocity, \(E\) = Modulus of Elasticity, \(u\) = Poisson’s ratio (0.24), \(f_{ck}\) = Compressive strength.

![Figure 4. Ultrasonic pulse velocity test](image-url)
3.1.2 Rebound Hammer test

Figure 5. shows the rebound hammer test which was conducted on columns of structure. The test was conducted as per IS 13311 (Part 2)[6]. The compressive strength was then obtained by using a graph which comes along with the hammer. The Rebound hammer test indicate that the compressive strength at maximum location ranges from 10 to 37 N/mm²[6]. The average compressive strength is 12 N/mm².

The test result of some columns interpreted after carrying out the rebound hammer test and Ultrasonic pulse velocity test are discussed in table 1.

![Figure 5. Rebound hammer test](image1.png)

**Table 1.** Ultrasonic pulse velocity test and Rebound hammer test results.

| Sr. No. | Description | Ultrasonic Pulse Velocity in Km/sec | Rebound Hammer Value | Remark | Compressive Strength in N/mm² |
|---------|-------------|------------------------------------|----------------------|--------|-------------------------------|
|         |             |                                    |                      |        | Ultrasonic Pulse velocity Test | Rebound Hammer Test |
| GROUND FLOOR |            |                                    |                      |        |                              |                      |
| 1       | Column 11   | 3.1                                 | 24.33                | Medium | 11.42                         | 17                   |
| 2       | Column 19   | 3.65                                | 28.33                | Good   | 26.67                         | 24                   |
| 3       | Column 115  | 3.54                                | 26                   | Good   | 23.60                         | 20                   |
| 4       | Beam 19-110 | 3.5                                 | 36.67                | Good   | 22.55                         | 37                   |
| 5       | Grid 15     | 2.9                                 | 23.33                | Poor   | 10.63                         | 15                   |
| FIRST FLOOR |            |                                    |                      |        |                              |                      |
| 1       | Column 21   | 2.94                                | 23.42                | Doubtful | 11.23                        | 15                   |
| 2       | Column 29   | 2.64                                | 23.66                | Doubtful | 7.30                         | 15                   |
| 3       | Column 215  | 2.65                                | 20.40                | Doubtful | 7.41                         | 19                   |
| 4       | Beam 29-210 | 3.2                                 | 16                   | Medium | 15.76                         | 10                   |
| 5       | Grid 25     | 3.01                                | 23.33                | Medium | 12.34                         | 15                   |
| SECOND FLOOR |            |                                    |                      |        |                              |                      |
| 1       | Column 31   | 3.65                                | 20.44                | Medium | 13.26                         | 10                   |
| 2       | Column 329  | 2.92                                | 23                   | Doubtful | 10.93                        | 15                   |
| 3       | Column 315  | 2.63                                | 20                   | Doubtful | 7.19                         | 10                   |
| 4       | Beam 39-310 | 3.1                                 | 23.33                | Medium | 13.88                         | 15                   |
| 5       | Grid 315    | 2.96                                | 21.11                | Doubtful | 11.54                        | 12                   |
| THIRD FLOOR |            |                                    |                      |        |                              |                      |
| 1       | Column 41   | 2.65                                | 19.33                | Doubtful | 7.41                         | -                    |
| 2       | Column 49   | 2.89                                | 20.66                | Doubtful | 10.48                        | 12                   |
| 3       | Column 415  | 2.55                                | 19.77                | Doubtful | 6.35                         | -                    |
We can consider, that the approximate grade of concrete is 10 MPa. Though the test results vary ±25%.

3.1.3 Carbonation Test

For determining the carbonation depth, the member of the structure was checked using a phenolphthalein indicator that appears pink as shown in figure 5, when it comes in contact with alkaline concrete having a pH value greater than 9 and is colorless at a lower level of pH. As per the pH and carbonation test on concrete, it is observed that the pH of cover concrete is reduced and the passive layer over the reinforcement is not intact. As per pH and carbonation test, the carbonation depth has crossed the reinforcement level and active corrosion is observed in reinforcement.

3.1.4 Half-cell potentiometer test

The probability of corrosion was determined by a half-cell potentiometer test. The test was performed as per ASTM C 876-91[7]. As per the Half-cell Potentiometer test on reinforcement, the readings were in range between –159 MV to –482 MV which indicates the active corrosion has started in reinforcement. Figure 7. shows the half-cell potentiometer conducted at different depth.

3.2 Analysis of Reinforced Concrete Structure.

Analysis was done using STAAD.pro software for determining the internal forces developed in the structure. The plan of the modal is as shown in figure 8. The internal forces developed due to dead load, live load, floor load and earthquake load were compared with the remaining capacity of structural elements. The current load capacity of the structure was low as compared to its initial design capacity due to deterioration. Loads considered in this analysis were dead load, live load, and earthquake load. To get the maximum internal forces in the concrete element, different load combination was considered as per Indian code. With help of visuals and the results obtained from STAAD.pro analysis, the strengthening scheme was proposed.
4. Strengthening Scheme

Depending upon the condition of structure, strengthening scheme was proposed to improve the present condition of structure.

4.1. Epoxy grouting for beam and column.

Epoxy grouting is adopted for crack repair. It can be performed with relatively unskilled personnel and can be used to seal fine pattern cracks and larger isolated cracks. It is used to seal the cracks against the ingress of moisture, chemicals, and carbon dioxide. Two-Component Low Viscosity Epoxy Resin is a very low viscosity epoxy injection grout material. It has high bond strength, Good tensile strength, low viscosity, and early curing.

The holes are drilled to inject epoxy or cement, the spacing of these holes depends upon the width of the cracks, the severity of damage, and dimensions of structural elements. The dust particle is removed from cracks using compressed air through all nipples in succession. The epoxy resin and hardener are pumped at 3 to 5 psi. The surface is then flushed using polymer-modified mortar.

4.2. RCC Column Jacketing.

RCC Column can be strengthened by Jacketing and by providing additional cage of lateral and longitudinal tie reinforcement around the column and casting a concrete ring, the desired strength and ductility can thus be built up. For this, the concrete cover is removed completely and grouting is carried out using cement or epoxy as a medium to fill cracks present in the column. Holes are drilled and shear connectors are fixed using chemicals. After that, the column surface is cleaned and vertical reinforcement and rings are placed as per drawing. A new epoxy-based bonding agent is applied and new concrete is cast using Micro Concrete.

4.3. Rust Remover and Passivator.

After removing loose rust by mechanical means such as wire brushing, chipping, hammering, etc. depending upon the extent of corrosion. Apply Rust Remover on the affected surface. Leave it for at least 24 Hr. after applying Rust Remover. Depending on the extent of bar corrosion and roughness of the surface, 1-liter chemical covers 7 to 8 m² of the plate-like monolithic surface[8].

4.4. Crack Filling.

To fill these cracks, first clean the surface from oil, dust, loose particles, etc. then moisten the surface and then fill the cracks using elastomeric Acrylic Crack filler using a spatula or putty knife. The surface is allowed to set for 24 hours and then the second layer is applied at an interval of 24 hours if the depth of crack is more than 10 mm.
4.5. **Waterproofing.**

Polymeric waterproofing is an alkaline material and compatible with concrete. It has also high strength flexural strength and extraordinary adhesion of polymer reinforces the high compressive strength property of the cementsations matrix.

Clean the surface and remove all laitance, dirt, paint, loose flakes, or any other foreign material using a vacuum cleaner or high-pressure jet or wire brushing. All honeycombed surfaces or cracks are to be repaired and filled. All it to set for 24 hours and then water jet 24 hours before application of polymeric waterproof. Make slurry, avoid forming any lumps and apply it on the damp surface using the brush. Apply 2 to 3 layers at an interval of 24 hours. Allow to set for 24-48 hours and cure it for 2 to 3 days.

4.6. **Waterlogged Basement.**

The basement is filled with water and as the Groundwater level is higher, the basement gets waterlogged. So here we are going to completely close the basement.

Firstly, the basement is completely dewatered using pumps. All the openings present in the basement are closed by constructing walls and holes are drilled on the slab to fill material. The filling used is Fly ash and it shall be cleaned of all rubbish, large size stone, vegetation, etc. Fly ash is then filled in the basement through these holes using compressed air. After the basement is filled, all the openings are then sealed using concrete and cured.

4.7. **Polymer repairs to damaged concrete. (Honeycomb areas)**

To repair damaged areas, first the loose concrete is removed and then it is cleaned with compressed air. After those 2 coats of steel protective coating is applied to the rebar to prevent further corrosion of rebar. The Polymer modified bonding agent is applied over the area and finally, a polymer-modified mortar is practiced over the surface in planks of 25 mm.

5. **Conclusion**

Generally, after construction of the structure, regular inspection and maintenance of the structure is neglected. It is essential to perform periodical structural audit by civil or structural engineer and act immediately. The success of repairs and retrofitting depends upon knowledge, proper diagnosis, and in-depth analysis of problems in building, proper repair practices and finally socio-economic considerations. The proper auditing and strengthening enhances the life span of the structure, prevents deterioration of building leading to sustainability.

The structural model considered for structural research deteriorated with age. Various Non-destructive tests were conducted on structure and thorough analysis was done, based on that strengthening scheme was proposed.

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