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Condition Assessment of Existing Concrete Building Using Non-Destructive Testing Methods for Effective Repair and Restoration-A Case Study

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Abstract

Buildings constructed during early 70's & late 80's of the last century in India are found to be in distressed conditions due to inadequate specifications and poor construction practices. The continuous monitoring of concrete structures using suitable NDT (Non Destructive Testing) methods and use of possible restoration methods help in a considerable reduction of the rate of deterioration of concrete structures thereby increasing the life span of structures. NDT methods have greater advantage in evaluating the uniformity, homogeneity, approximate compressive strength, durability, the extent of corrosion of rebars in concrete etc. of damaged structures. The objective of the present study is to enhance the life of 50 year old existing hospital building (Partly RC and Brick masonry) in Kurnool, Andhra Pradesh. Condition assessments are carried out through a visual, field and laboratory evaluation of samples collected from the structure and results are presented in this paper. The paper also highlights the assessment of strength and durability of concrete to evaluate the extent of distress and damage in the building. Besides visual inspection, the Non Destructive Evaluation covering UPV & Rebound Hammer values and Half Cell Potential with respect to the status of corrosion of reinforcing bars and chemical tests on selected un-distressed RC columns, beams, and slabs are also presented and discussed. The repair and strengthening techniques using the latest materials and possible restoration works such as column jacketing, shotcreting, anticorrosive coatings, etc. have been suggested to enhance the life of the structure.

Keywords: Distressed Condition; NDT Methods; Condition Assessment; Restoration Works.

1. Introduction

Concrete is one of the most versatile and widely used construction materials throughout the world. Reinforced concrete structures have to withstand environmental conditions throughout its life-span if properly prepared and placed. It has been demonstrated by the large number of concrete structures built over the last 100 years in different parts of the world.

The steel embedded in the concrete structure whether as reinforcement or prestressed tendon, being ferrous material, is prone to corrosion which cannot be totally eliminated. All developed countries have carried out necessary preventive measures including revision of the concrete codes by incorporation of suitable durability practices in seventies and eighties. However, this process has been very slow in India, even the basic concrete code IS: 456-2000, has not been fully updated for durability requirement. Steel reinforced concrete structures form an important part of our infrastructure. The combination of high compression strength of concrete and high tensile properties of reinforcing steel gives an ideal composite material which offers, compared to other materials, a wide range of applications in structural engineering.

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Buildings, slabs, beams, bridge decks, piles, tanks and pipes, all these structures are essentially made of steel reinforced concrete.

Corrosion is a destruction of material because of its reaction with the environmental conditions the most predominant among various factors of corrosion is the atmospheric corrosion which causes the rusting of steel. Appreciable corrosion starts when the relative humidity of the air exceeds around 65%. In dry, pure air and below freezing point of water there is no danger of the corrosion. Hence structural health monitoring is an important exercise to assess the damages occurring over a period of time. Non - Destructive testing (NDT) is used as an integral part of general structural health monitoring system. NDT methods help in the determination of quality and homogeneity of materials, without affecting the performance, serviceability of a structure during their evaluation. Failures in RC structures can be prevented through corrosion monitoring and early detection of cracks using various NDT methods.

Several evaluation methods are currently used to collect information about parameters that are related to structural performance including displacements, strains and stresses.

This information is combined with advanced post-processing tools to infer on the current operational state and remaining life. The choice of particular NDT method depends upon the property of concrete to be evaluated such as strength, corrosion, crack monitoring etc.

The factors influencing Corrosion of Reinforcement are namely,

- Quality of Concrete
- Cover Thickness of Concrete Over Reinforcement
- Condition of Reinforcement
- Effect of Environmental and other Chemicals
- Porosity of Concrete
- Effect of High Thermal Stresses
- Freezing and Thawing Condition
- Total Loss of Steel due to Corrosion
- Storage and Stacking Of Reinforcement Steel

Condition evaluation of a structure involves determination of excessive deflection of structural elements, misalignment, impact damage, excessive cracking, loss of concrete or loss of steel section that require a structural evaluation before repairing corrosion damage. This may lead to limiting the amount of break out permitted during repair, adequate time for concrete strength gain after the repair. Degradation processes that may indirectly contribute to corrosion of the reinforcement (freeze-thaw, sulfate attack, etc.) should also be considered. Distinction should be made between different parts of the structure where

a) Reinforcement is still passive, i. e. corrosion has not initiated since carbonation or chloride penetration has not reached the steel surface.

b) Reinforcement is corroding but the propagation is in the early stages, e. g. concrete cover is not cracked and reduction in cross section of rebars is negligible.

c) Corrosion of steel leads to loss of serviceability of the structure, e. g. due to cracking, spalling or delamination of the concrete cover and/or more than insignificant loss of rebar cross section.

The present paper focusses on condition assessment of an existing 35 year old hospital building and the possible rehabilitation works to enhance the life span of the structure with safety. The preliminary assessment of the condition of the structure is done by visual inspection, probing of cracks and spalls to see their extent, reinforcement cover measurements etc. In the second phase possible strength measurements, carbonation measurements, reference electrode measurements are done by taking samples for laboratory testing. Finally, combining the analysis of results of various NDT methods for assessing the quality of structures has been done and the possible repair and restoration works are suggested.

2. Literature Review

Many researches have been conducted worldwide to assess the deterioration of existing concrete structures. Non-destructive methods play an important role in the analysis such buildings. Many authors worldwide presented their studies on non-destructive evaluation techniques and possible strengthening techniques available from time to time for aged and deteriorated structures.

Gattulli and Chiaramonte [27] used the visual inspection method for the quality determination of a bridge for Italy railways. They conducted inspections on concrete, steel and masonry bridges. The damage levels associated with maintenance and repair was discussed. Four different simulation models have been proposed for the regular assessment of these structures. Abdulkader El Mir et al. [9] emphases on the limitations of rebound hammer method based on the response of the rebound index towards different parameters. The author conducts a series of experimental tests on 795 cubic specimens to understand the repeatability of the rebound index in several concrete type admixtures. The surface hardness test is conducted using the N-type Schmidt hammer according to European standard. The results of his experiment discussed on the parameters such as water binder ratio, the water-powder ratio, SCMs and admixtures. His experiments proved that the coefficient of variation of the rebound index has influence on the parameters such as water binder ratio, the water-powder ratio, SCMs and admixtures of the concrete cubes tested. Jin-Keun Kim et al. [10] determines the strength parameters of concrete and factors affecting the Rebound Number due to carbonation in concrete structures with his experiments. He has established relationships between the Compressive Strength for 28, 90, 180, and 360 days concrete cubes respectively and the Rebound Number. A new equation was derived considering the effect of carbonation on the Rebound Number in determining the strength reduction coefficient.

Abdulkader El Mir et al. [17] has conducted investigations to evaluate the compressive strength of concrete and boundary imitation of Rebound Number using Rebound Hammer equipment. Results showed that, from normally vibrated concrete to Ultra-High Strength concrete and the water powder ratio, the water-binder ratio, and the admixtures relatively has influence on the rebound index number and compressive strengths. Ourania Tsioulou et al. [11] studies shows, the evaluation of tensile strength and the Compressive strength using UPV and Rebound Hammer measurements. Author uses the combination of methods in his analysis. He concluded that the combined use of these methods offers higher accuracy where test errors were found to be below 10% in the determination of compressive strength and modulus of Elasticity. M. Yaqub et al. [12] has conducted experiments to determine the compressive strength in the existing RC columns damaged in a fire accident using UPV Test Method. His experiments showed the variation in compression strength of concrete when subjected to different temperature conditions. Maitham Alwash et al. [16] discuss the techniques like rebound hammer and the Ultra-Sonic Pulse Velocity test. The factors affecting these techniques and measures to develop effective methodology in improving strength parameters using synthetic simulation approach has been proposed. Veerachai Leelalerkiet et al. [13] has used Half-Cell Potential apparatus to determine the probability of rusting of steel in reinforced concrete slabs subjected to cyclic wet and dry conditions. 3D Boundary Element Method is used to study the parameters like, the rate of flow of current and the potential distributions. Corrosion states were evaluated using results of Inverse Boundary Element Method. The results were found to be insignificantly successful, when compared to the analytical results using Boundary Element Method. The results of Inverse Boundary Element Method analysis identify corroded areas more prominently.

Yun Yong Kim et al. [19] have used Half-Cell Potential Test method in his experimental studies to evaluate the crack in concrete when exposed to chloride attack. The test results are obtained considering the effects of water-cement ratio, crack width and cover depth. Anti-corrosive techniques to withstand chloride attack are proposed from the results. Jin Xia et al. [15], study show the performance of RC columns when it is embedded with corroded steel. 6mm and 20mm hot-rolled reinforcing steel bars were used in the RC column sections. The compressive strengths were determined using cubes of size (150X150X150) mm with same mix proportions. Corrosion was induced using the electrochemical process. The columns were tested for eccentric-compressive loading. Relationships concerning the average c/s area, strength loss, and the maximum crack width of concrete cover were established. The quantitative estimate of the residual compressive strength of the corroded reinforced concrete column was obtained using load-carrying capacity models. Lamya Amleh et al. [8] have conducted investigations on the existing Montreal Dickson Bridge. Spans of 0.25m by 0.25 m on four randomly selected 5 m by 6 m deck patches are considered for analysis. A detailed research was conducted to understand the reason behind the rapid deterioration of the bridge. J. Helal et al. [18] discusses the most common non-destructive test methods used in structural engineering industry. The limitations, potential, inspection techniques and interpretations are discussed. Katalin Szilágyi et al. [36] have developed of a constitutive model, i.e. SBZ-model that can formulate the surface hardness of the concrete. The relationship between the water–cement ratio, the Rebound Number and the compressive strength of concrete has been established considering 28days strength of concrete. It also relates to the depth of carbonation and its influence on the rebound index.

Shamsad Ahmad [37] discusses about various internal and external factors causing corrosion in RC structures. The rate of corrosion is measured using Linear Polarization Method for in-situ concrete. Corrosion Mechanism and parameters affecting corrosion in reinforced concrete structures are also illustrated. With the use of different models and experimental techniques, the enduring life of RC structures can be predicted. Eugen BRÜHWILER et al. [38] proposes three methods to reduce corrosion risk in concrete i.e. by providing sufficient cover thickness to concrete structures, or use of concrete with low permeability properties, or by reducing the early age cracking of concrete. Numerical models that allow the prediction of the initiation phase of corrosion and early-age cracking of concrete elements are also discussed in his study. The factors affecting the hydration rate of concrete and its permeability properties are also described in the paper. Tarek Uddin Mohammed et al. [39] discusses about, the corrosion of steel in RC structures when exposed to a marine environment. Experiments include evaluation physical and chemical properties of corrosion, presence of chloride ion, and permeability properties of concrete. He concludes, the W/C ratio has great influence on the magnitudes of corrosion. As the narrow cracks heals considerably fast in the marine environment, chances of reduction in corrosion rate can be seen. Viktor Urban et al. [40] paper deal with experimental tests on weathering steel bridges. The effects on the steel bar when subjected to exposed the surface, and damage of surfaces due liking water is discussed. It also explains the relationship and dependence factors between measured corrosion loss and the average thickness of corrosion products. Razmjoo et al. [41] studied the relationship between the location of the steel bar and the coarse aggregate present in concrete. In the experimental process there different samples were casted placing aggregates at three different distances from the steel bar.

Results showed that, the location of the coarse aggregate from the steel bar has significant influence on the chloride ion penetration and the initiation of corrosion in steel. It was concluded that, by decreasing the distance between the coarse aggregate and the steel bar can lower the initiation of corrosion in reinforced structures. M. Goueygou et al. [42] has conducted experiments on concrete cubes having surface breaking cracks. The combination of non-destructive test methods like Resistivity Method and Ultrasonic Pulse Velocity method has been used. Three different mix concrete specimens were used in his studies. Cracks were induced in the section using Three Point Bending Setup apparatus. He concludes as, both the tests was capable in detecting the main crack. However, a compound crack pattern and depth of the crack was not considerably analyzed. Ngoc Tan Nguyen et al. [43] studies involve the assessment of spatial variability, i.e. the non-homogeneity of mechanical and physical properties of concrete structures. It also briefs about the possible NDT methods used for the assessment of these structural components. The method of analysis adopted for the NDT measurement is the variographic analysis. He concludes that, combined NDT techniques developed has improved the evaluation of concrete properties and also the assessment of spatial variability in concrete structures.

3. Case Study

➢ **Project considered: Government General Hospital Building, Kurnool, Andhra Pradesh, India.**

The Department of Medical and Health of Andhra Pradesh government has listed old distressed buildings for their reuse and rehabilitation. The building is subjected to tropical environmental conditions. The consultant M/S Civil Aid Technologies, Hyderabad have been assigned to study and prepare a report on the status of the hospital building. Authors are part of this project under the postgraduate internship program.

Kurnool Government General Hospital was established in 1856 as a small hospital with only two wards. Gradually due to increase in number of patients, the hospital was spread and re constructed with various other wings in 100 acres of area, which includes a sophisticated medical college. There are 13 operation theaters and 65 wards that can accommodate around 100 patients at a time. It also comprises of Super-specialty block (G+3 floors), Trauma Care Center (G+1floor), Burn care unit, Cancer Block, Family Planning and Gynecology Block, Surgical Blocks, General OP Blocks, etc. are established with the help of central government funds. Burn care unit is provided with the centralized AC system and with various advanced facilities. Two Patients Shelter units inside and outside the hospital are constructed with toilets and bathrooms for the attendants of patients.

The critical block considered in this study is:

- **Block 1 (Family Planning and Gynecology Block):** Family Planning and Gynecology is around 30 year old building comprising G+1 floor. The portion of this block is constructed with load bearing walls with angular truss for roofing. The truss is covered with AC sheets. The corridors of this block are roofed with Madras Roofing System consisting of wooden purlins resting on the load bearing walls. The overall dimension of the building is 330×206.

- **Portion 1:** It consists of 41 columns of size $450 \times 750\ mm$ along the grid A2-A20 (Figure 1) and 2 columns of size $550 \times 950\ mm$ along the grid A21-C2 (Figure 1), and beams of size $300 \times 450\ mm$. The roof is supported by an angular truss section of size $60 \times 60 \times 5$ and purlins of size $50 \times 50 \times 5$ covered with AC sheets.

- **Portion 2:** It consists of 20 square columns of size $450 \times 450\ mm$ along the grid 1E-1F and 3E-3N (Figure 1). Beams are of size $450 \times 300\ mm$. The roof is supported by an angular truss section of size $60 \times 60 \times 5$ and purlins of size $50 \times 50 \times 5$ covered with AC sheets.

- **Portion 3:** It consists of 26 columns of size 450mmX750mm along the grid A1-A12, C1-C12, B1, B12 (Figure 1).Beams are of size $450 \times 300\ mm$ and $300 \times 450\ mm$ respectively. Roof is supported with RC slab system resting on the load bearing walls.

- **Portion 4:** It consists of 27 columns of size $450 \times 750\ mm$ along the gird E19-P19, D20, P20, and D21-P21 (Figure 1). Beams are of size $450 \times 300\ mm$. The roof is supported by an angular truss section of size $60 \times 60 \times 5$ and purlins of size $50 \times 50 \times 5$ covered with AC sheets.

- **Portion 5:** It consists of 42 columns of size $450 \times 750\ mm$ along the gird Q1-Q15, R1-R15, T1-T5, and S5-S1 (Figure 1). It also consists of square columns in the portico region of size $450 \times 450\ mm$. Beams are of size $450 \times 300\ mm$ and $300 \times 450\ mm$ respectively. Roof is supported with the RC slab system resting on the load bearing walls.
- **Portion 6:** It consists of 46 columns of size $450 \times 750\ mm$ along grid Q16-Q28, R16-R28, S16-25, and T25-T28 (Figure 1). Beams are of size $300 \times 450\ mm$. Roof is supported with RC slab system with load bearing walls.
- **Portion 7:** It consists of 30 columns of size $500 \times 100\ mm$ along the grid D24-P24, D28-P28 (Figure 1) and 26 columns of size $600 \times 1300\ mm$ along the gird D25-P28, D27-P27 (Figure 1). Beams are of size $300 \times 450\ mm$. Roof is supported with the RC slab system resting on the load bearing walls.

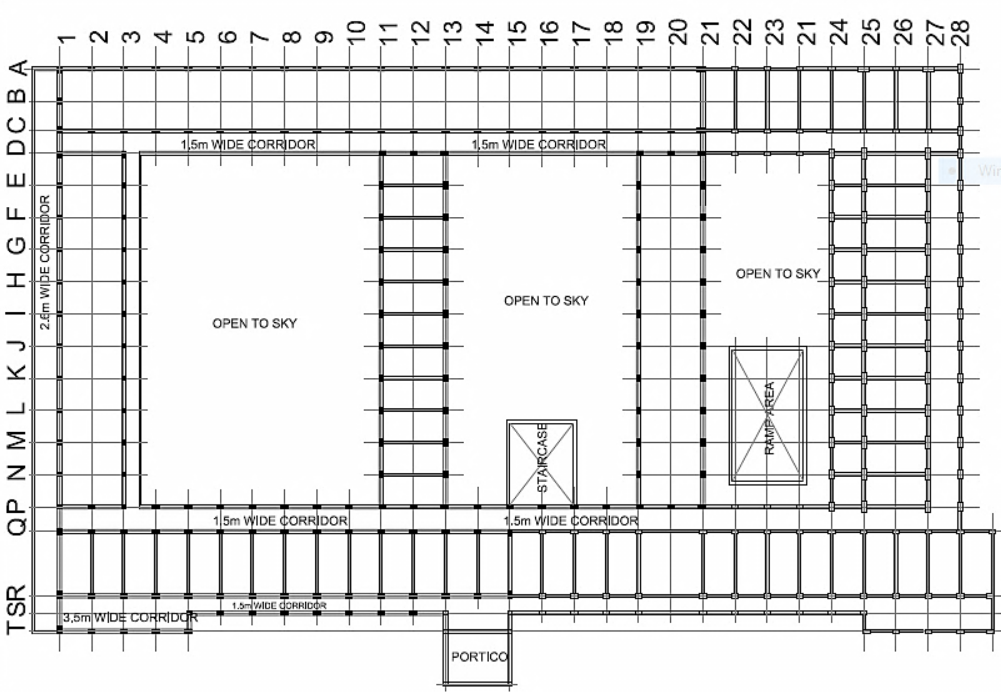

Figure 1. Plan of the Existing Building

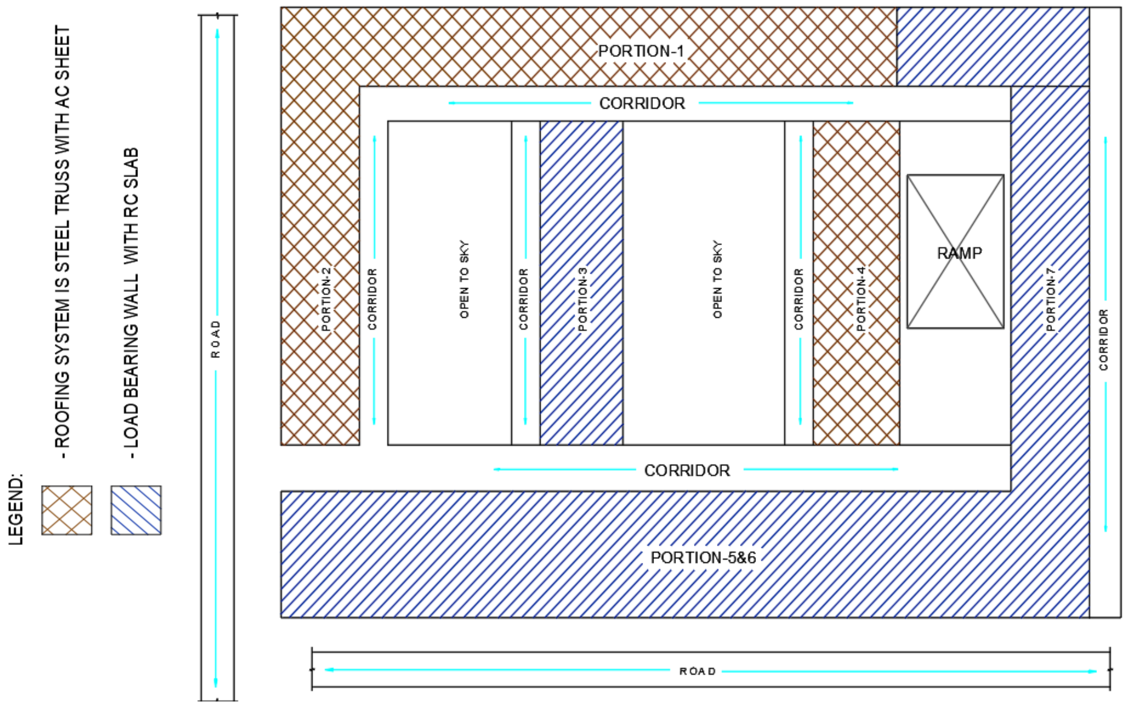

Figure 2. Structural detail of the existing building layout

Figure 3. No Plinth Protection

Figure 4. Loosening of Motor

Figure 5. Distressed in wooden members

Figure 6. Dampness in columns

Figure 7. Cracks near Expansion Joint

Figure 8. Damaged false roofing and Truss

Figure 9. In-situ Non-destructive Tests

The Figures 3 to 9. represents the present condition of the existing building.

4. Non-Destructive Techniques

In the present scenario, it is observed that many important reinforced and pre-stressed structures show distress within a short period. These conditions are usually inspected and restored only when the embedded steel is highly corroded, followed by cracking and spalling of concrete. Quality of structure can be maintained by Continues monitoring and conducting periodic surveys. In order to protect rusting and erosion of steel in reinforced concrete structures, few of the major non-destructive techniques are proposed in this study.

4.1. Visual Inspection

The following are the physical observations made during the inspection;

- Dampness was observed on walls below sill level at many locations.
- Growth of Vegetation was observed at a few locations nearer to the plinth.
- Dampness was observed on sunshades at many locations.
- Plinth protection was observed to be damaged at some locations.
- False ceiling was observed to be damaged at many locations.
- Separation crack was observed between CRS and brick masonry.
- Separation cracks were observed between masonry joints at a few locations.
- Corrosion cracks were observed.
- Spalling and exposure of reinforcement was observed in slabs at a few locations.
- Wooden purlins were observed to be decayed at some locations.
- Cracks were observed in the existing WPC on the terrace.
- Severe leakages & dampness was observed in the roof & walls of the newly constructed toilet block.
- It was reported that, severe leakage was observed from the expansion joint during monsoon season.

4.2. Rebound Hammer Test

Rebound Hammer Test is a quick method to evaluate the quality of concrete based on surface hardness of the existing structure. The rebound number gives the average surface compressive strength of the concrete. Rebound Hammer Test was carried out on all accessible locations of R.C. slab panels, beams, and columns such as Slab panel b/w grids Q4Q5 & R4R5, Slab panel b/w grids Q9Q10 and R9R10, Slab panel b/w grids Q10Q11 and R10R11, Beam along the gird R10-R11, Beam along the grid Q7-Q8, Beam along the grid R12-R12, Column along the grid Q6, Column along the grid Q11, Column along the grid R11 (Figure 1) in order to assess the surface hardness / quality of in-situ concrete. Initially the surface was prepared by removing the Plaster and dusting the surface to get better results. The test was conducted by using 'Schmidt Rebound Hammer' from M/s. Proceq, Switzerland. The results are presented in Figure 10. and corresponding reference strength is presented in Table 1.

Table 1. As per IS: 13311-(Part-II)-1992 (Reaffirmed in 2013) and Instrument manual furnished by M/s. Proceq, Switzerland

Rebound Number	Estimated Compressive Strength Range (N/Sq.mm)
22 to 26	10 to 14
26 to 30	14 to 18
30 to 34	18 to 22
34 to 38	22 to 26
38 to 42	26 to 30
42 to 46	30 to 34

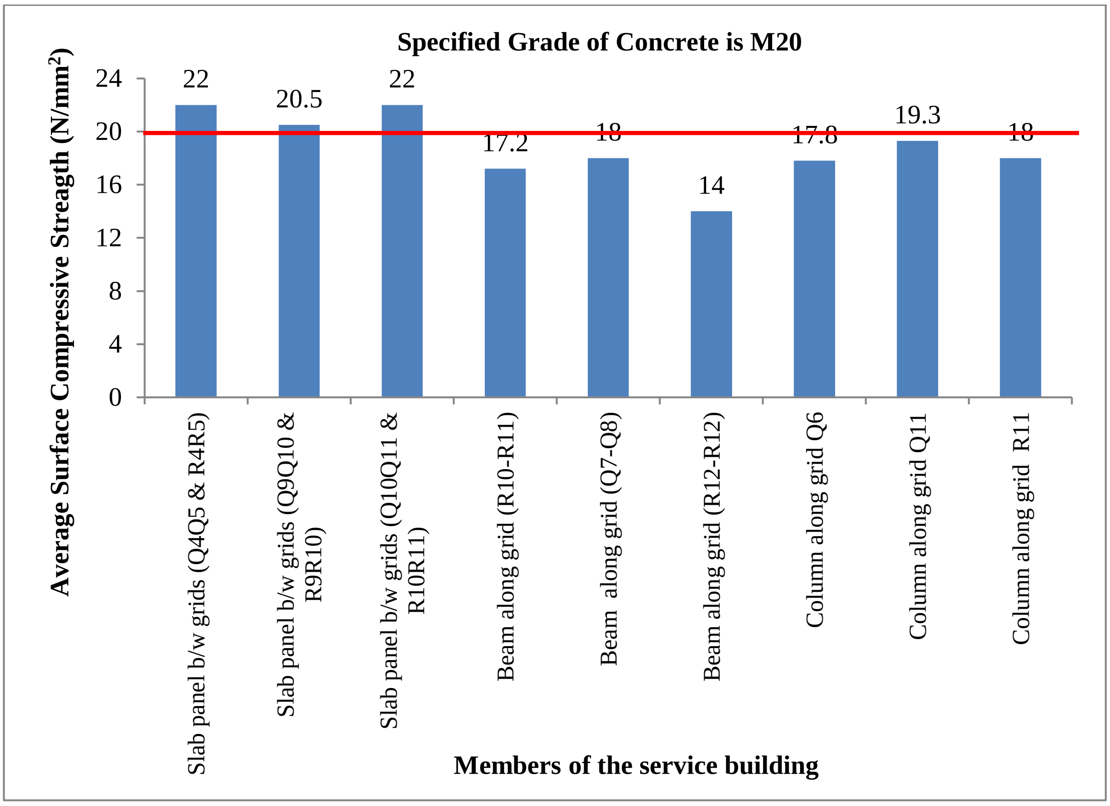

Figure 10. Shows Average Surface Compressive Strength of RCC Columns. Beams and Slab

4.3. Ultrasonic Pulse Velocity Method

Ultrasonic Pulse Velocity Test is being extensively used to assess the quality of concrete in general. This test is generally used to check uniformity of concrete, determination of cracks in the interior concrete, honeycombing and assessment of concrete deterioration.

Ultrasonic Pulse Velocity Test was conducted on accessible locations of R.C. Beams and Columns such as Beam along grid Q5-R5, Beam along grid Q11-R11, Column along grid R1, Column along grid Q1, Beam along grid Q12-R13, Column along grid Q19 (Figure 1). The transducers were coated with grease and placed on the opposite side of beams and columns for better electrical conductivity. Direct / Indirect method of scanning was adopted at site. The tests were conducted using 'PUNDIT LAB+' (Portable Ultrasonic Non-Destructive Digital Indicating Tester) equipment from M/s. Proceq, Switzerland. The results are presented in Figure 11. and the corresponding reference quality grade chart is presented in Table 2.

Table2. Concrete quality grading for different velocity criterion as reproduced from IS: 13311 (Part 1) – 1992 (Reaffirmed 2013)

Pulse Velocity (km/sec)	Concrete Quality Grading
Below 3.0	Doubtful*
3.0 to 3.5	Medium
3.5 to 4.5	Good
Above 4.5	Excellent

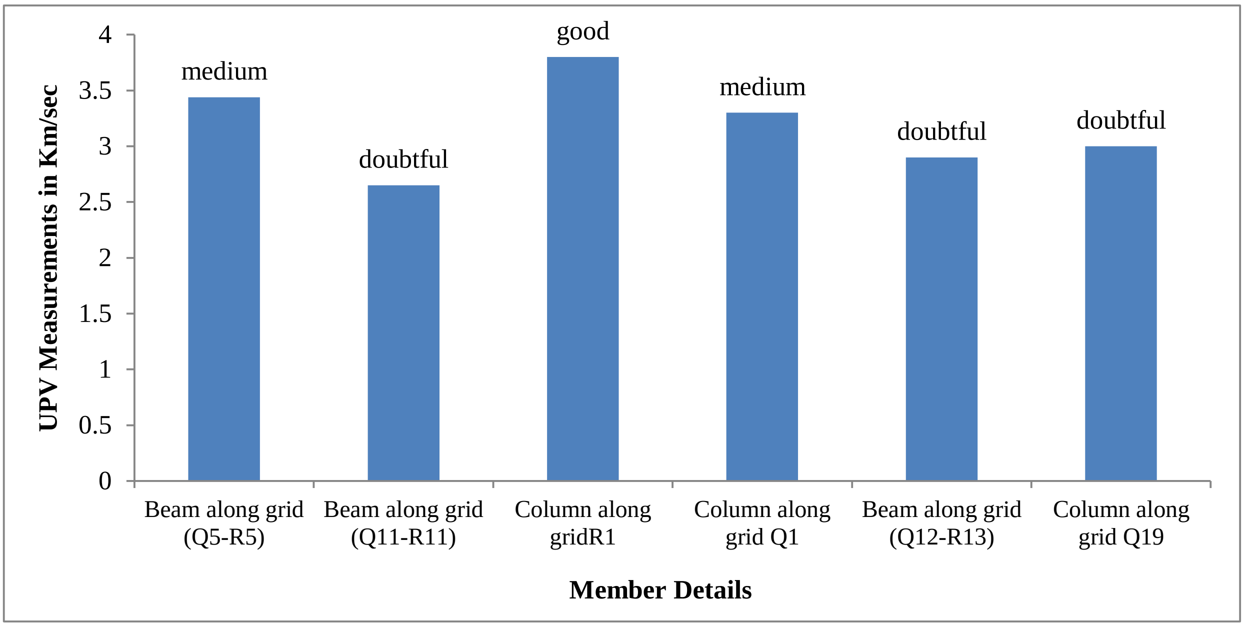

Figure 11. Ultrasonic Pulse Velocity Measurements results on selected members

4.4. Half-cell Potential Test

In order to assess the extent of corrosion in reinforcing bars of R.C members, ‘Half-cell Potential Difference Measurement test’ was carried out on randomly selected accessible locations of R.C members. The test was conducted using copper-copper sulphate half-cell solution. The test results are presented in Figure 12.

Table 3. As per ASTM C876-91 Standards

Potential over an area	Most likely outcome
more positive than -200MV	90% probability that no reinforcing steel is corroded at the time of test
-200 to -350 MV	corrosion activity of the reinforcing steel
more negative than -350 MV	90 % probability that reinforcing steel is corroded

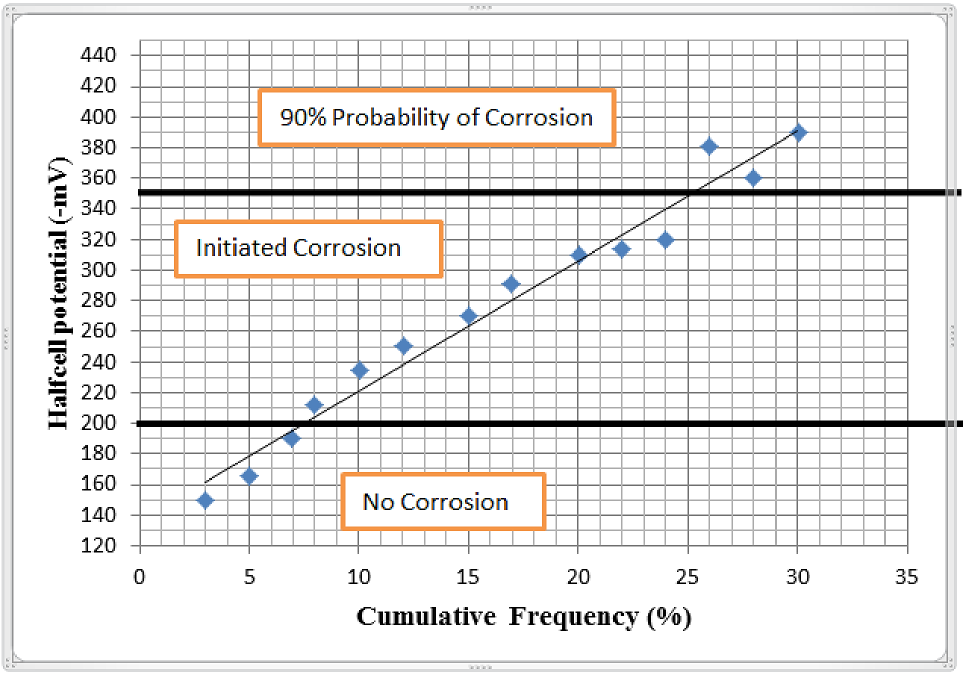

Figure 12. Half-cell Potential Test Results of selected Members

4.5. Carbonation Depth Measurements

To assess the extent of carbonation, i.e. the loss of alkalinity (which is essential to protect the steel against potential corrosion) in the cover concrete, colorimetric test was carried out on randomly selected accessible locations of R.C members such as Slab panel b/w grids Q4Q5 and R4R5, Slab panel b/w grids Q10Q11 and R10R11, Beam along grid R10-R11, Beam along grid Q7-Q8, Column along grid Q6, Column along grid Q11, Slab panel b/w grids Q9Q10 and R9R10, Beam along grid Q12-R12,Column along grid Q11 (Figure 1) using Phenolphthalein as indicator in dilute methyl alcohol solution. This test was carried out by removing the plaster and cover concrete to the required depth. The exposed area was then drenched with the sample solution prepared to check the amount of carbonation. The test results are presented in Figure 13.

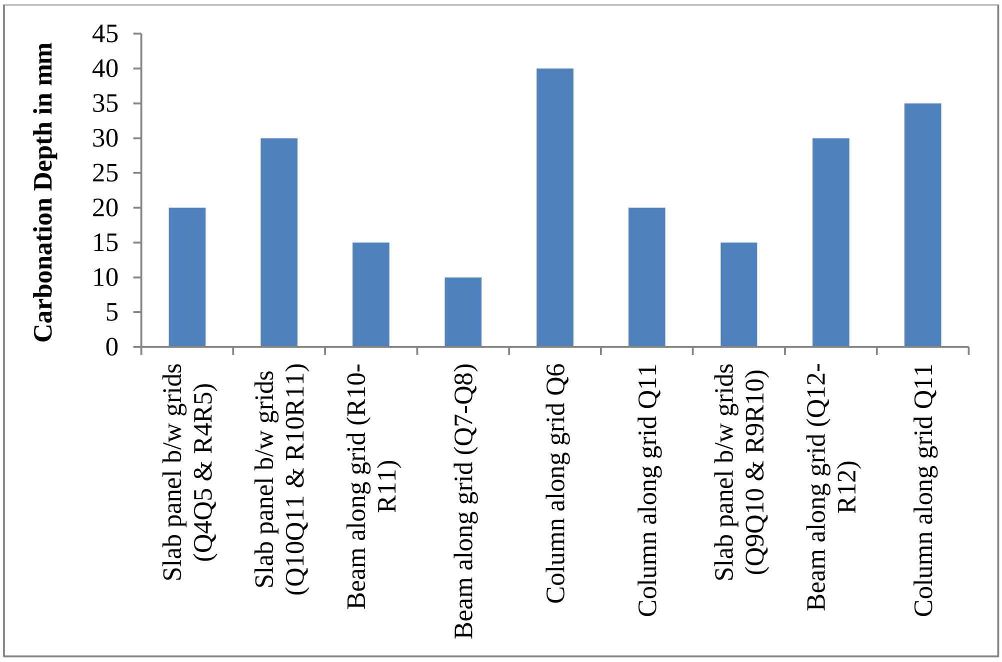

Figure 13. Carbonation depth measured at different members

4.6. Chemical Testing on Hardened Concrete using Core Cutting Method

4.6.1. Determination of Sulphate

Sulphate determination test is conducted to estimate the amount of sulphates present in concrete. The presence of higher amount of sulphates will result in causing deterioration of concrete due to the reaction of calcium with the excess sulphates present. The quantity of sulphates in concrete is expressed as percentage of sulphates by weight of concrete. The permissible limit of the test is 4.0%.

4.6.2. Determination of Chloride

Chloride determination test is conducted to know the amount of chlorides present in concrete. The presence of higher amount of chlorides results in corrosion of rebars. The permissible limit of the test is 0.6 kg/cum.

4.6.3. Determination of pH Level in Concrete

The pH level of fresh concrete generally ranges from 12 to 14. Due to the loss of alkalinity and the carbonation, the pH value of concrete will be reduced considerably. If the pH level in the structure falls below 10, then the alkalinity present in the concrete will not be adequate to protect the rebars against corrosion leading to deterioration of the structure. The results of Chloride test and pH test values are presented in Figures 14 and 15. respectively.

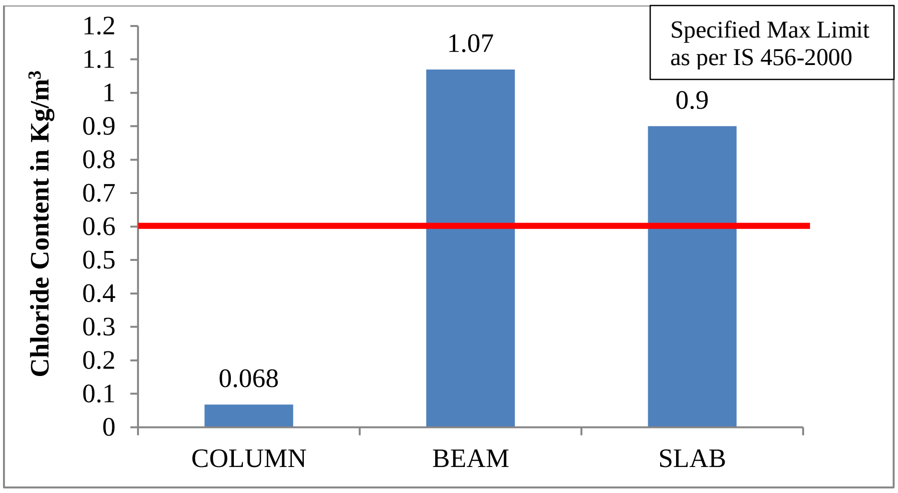

Figure 14. Shows chloride content of concrete powders extracted from Different member

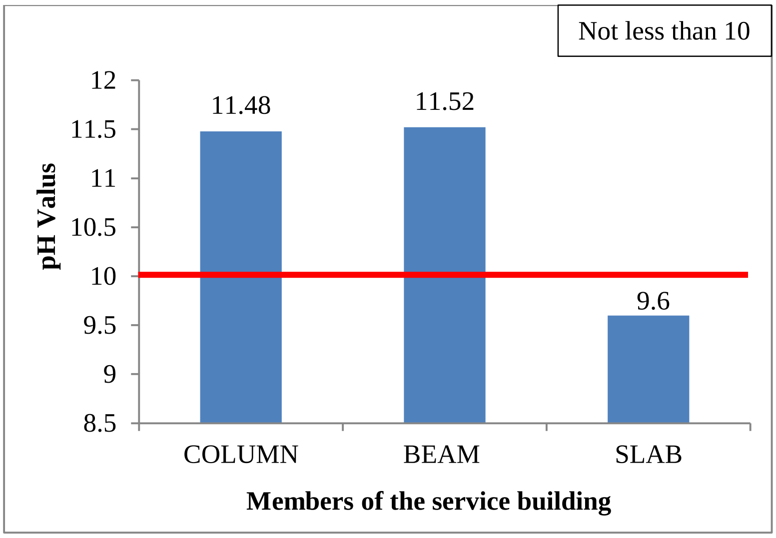

Figure 15. pH values of concrete powders extracted from Different members

5. Results and Discussion

- Based on the results obtained from Figure 10. for the Rebound Hammer Test conducted on selected structural members of the building, it is inferred that the strength of the cover concrete of R.C Slab panels in Ground floor is only satisfactory and also at few locations delamination of cover concrete was observed. The results were concluded in reference to Table 1.

- The results of Ultrasonic Pulse Velocity Test obtained from Figure 11. inferred that the quality of in-situ concrete in the tested locations of the R.C. beams in Ground Floor was found to be “Medium to Good” grade, as per Table 2.
- The Half-cell Potential Difference Measurement Test, was carried out on the selected RC members and the results obtained from Figure 12. inferred that, the corrosion of reinforcing bars in the structure was observed to in the “Initial Stage” (where no corrosion was observed) but in the lintel beam it was observed to be in the “Moderate Stage” (where corrosion was observed) with a need of proper supervision. The results were concluded in reference to Table 3.
- The Carbonation test results obtained from Figure 13. showed that the cover concrete in the tested R.C. Slabs and beams was carbonated up to reinforcement level and initiation of corrosion can be observed.
- As per the results obtained from Figure 14, chloride content was not the main reason for corrosion since the values were observed to be in considerable limits. Based on the age and extent of damage suitable restoration measures are suggested. The pH values were seen to be in considerable range with reference to the Figure 15.

6. Repair And Restoration Measures

The building investigated in the study consists of many distressed structural members leading to the corrosion of reinforced steel. In order to increase the residual life of this structure suitable repair and restoration measures have been proposed based on the damage in the respective structural members.

The building investigated in the study consists of many distressed structural members leading to the corrosion of reinforced steel. In order to increase the residual life of this structure suitable repair and restoration measures have been proposed based on the damage in the respective structural members.

a) Replacing of existing AC sheets in the corridor region:

In corridor areas the existing AC sheets at the first floor level shall be replaced with metal sheets and the damaged wooden joists shall be removed and replaced with new wooden joists with existing dimensions.

b) Treatment for distressed madras roofing in the corridor region:

In view of severe distress observed in the rear side corridor region of Portion -7 consisting of madras roofing system with wooden rafters, it is recommended to remove the madras roofing system. It shall be replaced with R.C precast slab panels with structural steel (ISMC) beams.

c) Treatment for Dampness and Spalling of cover concrete in slab panels:

In view of the dampness and spalling of cover concrete in slab panels, it is recommended to remove the existing plastering & loosen the cover concrete up to the extent of distress in a definite shape, i.e. square / rectangle. After a thorough cleaning of the surface, if there is any presence of corroded reinforcement, it is recommended to apply anticorrosion chemical paints to the rebar and then the portion shall be redone using polymer modified mortar.

d) Treatment for Damp patches & Peeling of plaster in Walls:

The deteriorated plaster on masonry walls at exterior face of the building shall be totally removed by gentle chipping. The mortar joints in walls shall be deep racked and repointed with CM 1:4 as per standard practice followed by re-plastering with CM 1:6 mixed with water proofing agents.

e) Treatment for Expansion Joint:

In view of leakages from the expansion joint, it is recommended to clean the joint and fill it with Polyurethane sealant and redo the portion as per IS 5256-1992 provisions.

f) Treatment for CRS masonry:

In view of dampness observed in CRS masonry, it is recommended to remove the loosen mortar between the masonry joints and redo it with cement mortar prior to grouting.

g) Treatment for Terrace Slab:

To seal the cracks and also to improve the durability, it is recommended to provide reinforcement concrete screed on terrace integral with providing fillet at required corners of the slab.

h) Strengthening beams and columns:

- RC beams can be strengthened by providing additional cage of longitudinal and transverse reinforcement around the beam and casting the concrete. The stirrups can be held in position by drilling holes into the slab.
- The strengthening of RC beams can also be done by inducing prestress to counteract the opposite moments encountered during loading. To induce this prestress, wires are introduced on both sides of the web and are anchored against the end of the beam through a steel plate.
- Inadequate sections of RC column and beams can also be strengthened by removing the cover concrete up to the reinforcement level and welding new steel to present rebar with the replacement of cover concrete. Initially the surface shall be roughed and prepared for the effective replacement of new steel with the introduction of grooves to facilitate shear transfer.

7. Conclusion

The present paper focused on the condition assessment, safety evaluation and possible repair and restoration methods for existing aged RC building.

- Visual inspection showed that most of the region in the building is subjected to distress due to spalling of concrete cover; cracks near expansion joint, dampness and initiation of corrosion in structural members have led to deterioration of the structure.
- The proper maintenance and periodic surveys helps in the restoration of aged RC buildings. The cracks in concrete appeared on the concrete surface due the chemical reaction can be eliminated by using proper grade of concrete, curing and good compaction.
- Knowing the probability of corrosion, the buildings can be restored by using different chemical treatments proposed for steel. The embedded steel can also be protected using cathodic protection of steel method, but the process may not be cost effective.
- Coating over steel bars is a short time solution for buildings. This results in causing weak bonding between steel and concrete. It is always recommended to use steel before it reacts with the environment.
- The use of polymer modified mortar, paints with water proofing compounds on the surfaces affected to dampness and distress results in reuse of these building with minimum expenditures.
- It can be seen that detailed visual inspection and Non Destructive Testing (NDT) play an important role in condition assessment of existing buildings. It is emphasized that using suitable NDT methods along with thorough observations we can understand the level of distress and with proper restoration measures under technical supervision the residual life of the structure can be enhanced.

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