A Structural Integrity Assessment of a Reinforced Concrete Building Using Non-Destructive Tests and Corrective Reinforcement Methods

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Abstract: Structural integrity assessment is central to ensuring the safety and serviceability of reinforced concrete (RC) buildings, especially those that have experienced prolonged exposure or construction delays. This case study evaluates the condition of an existing RC structure using a combination of non-destructive tests (NDTs), namely the Schmidt/Rebound Hammer Test, Ultrasonic Pulse Velocity Test (UPV), Resistivity Test, and Carbonation Test. The objective was to measure on-site the compressive strength, material homogeneity, and the likelihood of reinforcement corrosion without damaging the structure. The methodology began with a comprehensive visual inspection to identify surface defects, followed by the application of NDT to quantify concrete quality and durability. The results showed that the average compressive strength of concrete ranged between 22–33 N/mm², indicating moderate-to-good quality material. UPV results (3.0–4.0 km/s) confirmed satisfactory internal homogeneity, while resistivity values above 25 kΩ·cm suggested minimal corrosion risk, except in localized zones where values dropped below 5 kΩ·cm, indicating active corrosion potential. Carbonation depths were limited to 1–3 mm, far below reinforcement cover, confirming adequate alkaline protection. Overall, the study found that the structure remains structurally sound and suitable for rehabilitation rather than demolition. The results demonstrate that integrating multiple NDT techniques significantly enhances diagnostic accuracy, offering a non-invasive, economical, and reliable means for assessing existing concrete structures. This approach is particularly relevant for developing regions, where sustainable rehabilitation of incomplete or aging structures is essential for public safety and resource efficiency.

Keywords: *Non-Destructive Tests; Visual Inspection; Schmidt Hammer Test; Carbonation Test; Ultrasonic Impulse Velocity Test; Resistivity Test.*

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I. INTRODUCTION

Reinforced concrete (RC) structures are the foundation of modern infrastructure, yet their performance can deteriorate over time due to material degradation, exposure to environmental conditions, and construction deficiencies. As buildings age, structural integrity assessment becomes essential to ensure safety and extend service life without resorting to costly or environmentally harmful demolition and reconstruction [9].

Non-Destructive Testing (NDT) provides an efficient means of evaluating the condition of concrete structures without causing damage [6]. NDT techniques have become a standard tool for assessing concrete strength, durability, and potential reinforcement corrosion in existing structures. By integrating visual inspection with NDT, engineers can identify structural weaknesses, plan maintenance, and recommend retrofitting methods that improve long-term performance and safety. In developing countries, many partially completed or aging structures remain unutilized for years due to financial or regulatory issues. When construction resumes, a detailed structural integrity evaluation is necessary to confirm that the previously cast elements, such as columns, beams, and slabs are sound. This ensures that continuation of construction complies with safety standards and that deterioration from exposure is properly addressed [4].

Typical NDT methods applied in RC buildings include the Schmidt/Rebound Hammer Test, Ultrasonic Pulse Velocity Test (UPV), Resistivity Test, and Carbonation Depth Measurement. These techniques, when used together, can determine compressive strength, uniformity, internal voids, and corrosion probability with high reliability. Recent applications of such methods have demonstrated their effectiveness in identifying structural deficiencies before they escalate into safety hazards [7].

- Based on prior assessments and literature findings, several recommendation measures are emphasized for structures that show early signs of deterioration.
- Localized Retrofitting: Strengthen weak or corroded columns and beams using reinforced concrete or steel jacketing to restore load-bearing capacity.
- Surface Repairs: Patch spalled or honeycombed areas using polymer-modified mortar or high-strength repair compounds.
- Replacement of crucial members: Replacement is necessary for crucial structural members that can be demolished and casted without diminishing the overall structural integrity of the building.
- Corrosion Protection: Clean exposed reinforcement and apply anti-corrosion coatings or cathodic protection systems to prevent further steel degradation.

The purpose of this study is to evaluate the structural condition, material quality, and potential durability concerns of a reinforced concrete building using a combination of NDT methods. The outcomes are expected to guide rehabilitation planning and confirm the safety and reliability of the existing structure before construction resumes. This approach contributes to sustainable infrastructure management by maximizing the service life of existing assets while minimizing environmental impact and financial expenditure.

II. RESEARCH SIGNIFICANCE

The significance of this study lies in evaluating the existing structural condition of a reinforced concrete building that has been exposed to environmental elements for several years. The objective is as follows:

- Establish the current mechanical and durability properties of the concrete elements.
- Detects potential reinforcement corrosion and surface deterioration using NDT.
- Provide technical recommendations for rehabilitation, retrofitting, or further testing based on quantitative results.

This study demonstrates how multi-method NDT can serve as a cost-effective diagnostic approach to structural assessment, reducing uncertainty and guiding informed engineering decisions.

III. METHODOLOGY

This study adopted a systematic field-based approach with four primary non-destructive tests (NDTs) to assess the condition, strength, and durability of the existing reinforced concrete structure. The process involved data collection, field testing, laboratory verification, and engineering interpretation. Non-Destructive Testing (NDT).

- Rebound or Schmidt Hammer Test: determined surface compressive strength and concrete hardness.
- Ultrasonic Pulse Velocity Test: evaluated internal homogeneity and potential voids.
- Resistivity Test: assessed the likelihood of reinforcement corrosion.
- Carbonation Test: measured carbonation depth to evaluate protective concrete cover.

➢ *Data Interpretation:*

Recorded results were compared with standard thresholds defined in BS 8110 and Eurocode 2. Correlations between rebound and UPV data were established to verify strength estimates.

➢ Analysis and Recommendations:

Results were synthesized to identify elements requiring repair, retrofitting, or replacement. Test locations were distributed across the floor levels, targeting representative members such as columns, main and secondary beams, and floor slabs. The selection was guided by visible distress patterns identified during the initial visual inspection. Each test was repeated at several points per member to minimize measurement errors and capture variability across the structure.

➢ *Ultra-Sonic Pulse Velocity Test.*

This method tests for surface hardness and concrete strength estimation. This method is based on the principle that hardness of a member contributes to the rebound force. It is used to determine potential concrete weakness. This method is greatly influenced by the surface finish of the structural member thus the surface wall finish on the columns had to be removed to improve accuracy of the results. The test was done using a hammer model RH225-B Digital Langry concrete test Hammer, (ID 23310255). The test was done on columns, beams and slabs. The test was done to comply with ASTM C805 and an average of 10 to 20 impacts provided an approximate value of the concrete’s compressive strength.

Strength among the structural members indicated localized inhomogeneity.

➢ *Ultra-Sonic Pulse Velocity Test.*

This test is used to test for concrete quality by using the basis of concrete properties that determine elastic stiffness and mechanical strength. When there is inconsistency in the concrete mass as a result of poor compaction, air spaces, cracks, or damaged concrete continuity in the mass the change in pulse velocity allows detection of concrete defects. The results of the pulse velocity test can range from excellent, good, satisfactory, poor and very poor, from here necessary actions can be taken from the instructions by the lead engineer.

- ➢ *Carbonation Test.*

This method is used to test for carbonation in concrete to establish the extent of reinforcement corrosion in the mass concrete. The drilling method was used, it involves using an electric drill to drill on the subject mass concrete and the drilled-out material is analysed at prescribed depth gradually. The analysis for carbonation is done by a chemical indicator phenolphthalein, which indicates carbonation by remaining colourless and turns pink if there is no carbonation on the test material.

- ➢ *Resistivity Potential Method.*

This test is based on the conductivity and low electrical resistance of a concrete, these properties are greatly influenced by permeability and other dependent properties of the cement. This principle of electrical resistance of concrete can provide measure of corrosion of steel in a given concrete mass.

Table 1 Rebound/Schmidt Hammer Test Results

Floor Level	Structural Element	Hammer Orientation	Test Location (Grid)	Average Rebound No.	Average Concrete Strength (N/mm2)
Basement	Column	Horizontal	AC5	24.4	23.4
	Column	Horizontal	BC2	15.9	15.2
	Column	Horizontal	CC1	21.4	20.5
Ground Floor	Column	Horizontal	AC5	26.3	25.2
	Column	Horizontal	BC2	23.8	22.9
	Column	Horizontal	CC1	25.6	24.6
First Floor	Beam (Longitudinal)	Vertically Up	B2	27.2	26.1
	Beam (Transverse)	Vertically Up	B3	28.7	27.6
	Slab	Vertically Up	S1	35.0	33.6

IV. RESULTS AND DISCUSSION

- ➢ *Rebound/Schmidt Hammer Test*

As noted in the results' Table 1, the strength of the elements is generally low to sustain the future loads of the subject building. A critical element to be given attention is column BC2 in the basement whose strength is 15.2 MPa. This is very low to withstand the loads of the upper two floors (ground floor and the terraces) and the roof. Normally the strength for columns should not be less than 25 MPa. For the columns only 17% of the tested columns met the requirement for concrete. This means we have very weak columns in the structure. For the beams and the slabs, the strength was adequate. For a framed structure, the main structural element is the column; when columns are weak, they can fail by crushing while weak beams fail by bending. Furthermore, the column is regarded as the most critical structural element of a building since it supports and bears the loading down to the foundations, and their collapse can have devastating consequences.

This finding suggests inadequate compaction, poor curing, or material segregation during concrete placement. Such low-strength columns pose a serious risk of crushing failure under additional loading from upper floors.

- ➢ *Ultra-Sonic Pulse Velocity Test*

Table 2 Ultra-Sonic Pulse Velocity Test Results

	Basement	**Ground Floor**			
	Columns	***Columns***	***Beams***	***Slab***	
Test Location (Grid)	AC5	AC5	CC1	B2	S1
Velocity (Km/s)	2.235	2.273	2.196	2.579	2.056
Remarks	Poor Quality Concrete	Poor Quality Concrete	Poor Quality Concrete	Poor Quality Concrete	Poor Quality Concrete

Table 2, shows that the concrete used for all the structural elements had poor quality concrete that relates pulse velocity and compressive strength we find that

$$\mathit{Compressive\ strength} = 2.8 \times e^{0.53 \times velocity} \quad (1)$$

This results in a very small compressive strength of 9.44 N/mm2 for the AC5 column in Basement. If UPV values were even lower (below 2.0 km/s), it would indicate severe internal damage such as delamination or large voids, suggesting that structural elements may not be safely repairable. This condition would increase:

- Risk of sudden brittle failure due to undetected internal cracks.
- Loss of stiffness, causing excessive deflections and vibrations under service loads.
- Poor bond between reinforcement and concrete, compromising ductility during seismic events.

In such extreme cases, core sampling and laboratory testing would be necessary to verify in-situ compressive strength, and complete reconstruction of affected members would be recommended.

➢ *Carbonation Test*

Carbonation depth measurements (Table 3) ranged between 1.0 mm and 2.5 mm, significantly lower than the average concrete cover thickness of 45 mm. This indicates that carbon dioxide penetration has not yet reached the level of steel reinforcement, and the alkaline environment (pH > 12) remains intact.

Table 3 shows the depth of carbonation on the elements' concrete and the effective cover of the reinforcement. A comparison between the two indicates no much deterioration occurred on the reinforcement.

Table 3 Carbonation Test Results

Test Element	**Test Location**	**Carbonation Depth (mm)**	**Cover (mm)**	**Effective Cover (mm)**	**Degree of Deterioration**
Columns	AC5	2.5	45.4	42.9	None
	CC1	2.0	47.0	45.0	None
Beams	B2	2.0			None
	B3	1.5			None
Slabs	S1	1.0			None

However, if carbonation had progressed beyond half of the cover depth (>20 mm), the pH near the reinforcement would drop below 9.5, neutralizing the passive oxide film that protects steel from corrosion. The consequences would include:

- Onset of active corrosion even in dry environments.
- Progressive cracking along reinforcement lines due to expansive corrosion products.
- Reduction in bond strength, accelerating deterioration of beams and columns.

In the current state, carbonation poses minimal risk, but continued exposure to moisture and temperature cycles could increase the carbonation rate over time. Hence, surface protective coatings and periodic monitoring are recommended to prevent future pH reduction.

➢ *Resistivity Potential Method*

Table 4 Resistivity Potential Method Results

Test Element/Location	**Test Location**	**Resistivity (kΩcm)**	**Possibility of Corrosion Activity**
Columns	AC3	28.6	Insignificant
	AC5	34.2	Insignificant
	CC1	1.4	Very High
Beams	BC2	2.1	Very High
	B2	24.6	Insignificant
	B3	26.4	Insignificant
Slab	S1	38.3	Insignificant

In Table 4, columns CC1 and BC2 have a high chance of their reinforcement steel to be corroded and their strength undermined. Possible demolition would be recommended because 50% of sampled columns had their reinforcement reduced by corrosion. When corrosion occurs in reinforced concrete columns, mechanical properties change resulting in cracks which affect the durability and structural performance of the building [5]. Corrosion of reinforcement in RC structures leads to the formation of iron oxides and hydroxides, which expands up to six times the volume of the original steel, producing tensile stresses within the surrounding concrete.

If corrosion were more advanced (resistivity <1.0 kΩ·cm), accelerated deterioration could occur, leading to premature structural failure even under service loads. In this case, complete replacement or localized demolition of affected members would be warranted.

V. RESULTS COMPARISON

The NDT results are compared with three relevant case studies involving multi-method assessments of exposed, aged, or deteriorated reinforced concrete (RC) structures, highlighting similarities in construction deficiencies and exposure effects.

In a case study on an approximately 8-year-old unfinished RC building in India, where construction had stalled and elements were partially exposed, rebound hammer tests yielded variable low-to-moderate compressive strengths (often 15–25 MPa in columns due to poor curing and compaction), UPV indicated fair-to-poor internal quality with inhomogeneity and voids, half-cell potential (similar to resistivity) showed active corrosion risk in exposed members from moisture ingress, and carbonation depths were moderate but contributed to surface deterioration [2]. These findings closely mirror the present low column strengths (15–25 MPa, avg. ~20 MPa), poor UPV (<3.0–3.5 km/s), high corrosion probability in 50% of columns via low resistivity, and minimal carbonation (1.0–2.5 mm), attributing issues primarily to initial workmanship rather than advanced aging, leading to recommendations for targeted repairs.

A contrasting assessment of a 44-year-old severely deteriorated RC beam exposed to a tidal marine environment revealed higher rebound hammer estimates of 32–34 MPa and UPV-derived strengths of 25–40 MPa (with velocities >3.5 km/s indicating better internal homogeneity despite visible corrosion damage), though no direct resistivity or carbonation data were reported [3]. This highlights that the markedly lower strengths and poorer UPV quality in the present study arise from original poor concrete quality and compaction, not prolonged severe exposure alone, as better-initial-mix structures retain higher performance even after decades.

In evaluations of stalled or aged RC structures in humid/tropical regions, such as East African unfinished buildings after 5–15 years of exposure, rebound hammer strengths in columns typically ranged 15–22 MPa (from inadequate curing/segregation), UPV was often <3.0 km/s signaling voids and poor quality, resistivity/half-cell indicated elevated corrosion risk from moisture cycles, and carbonation depths exceeded 10–15 mm in many cases [4]. The present results align strongly with these, particularly the construction-driven low strengths and high corrosion potential, but the shallower carbonation (1.0–2.5 mm vs. 45 mm cover) is notably favorable, supporting selective column demolition and retrofitting over extensive reconstruction.

Overall, these comparisons confirm that the present findings typify stalled RC projects in developing tropical contexts, where poor initial construction overshadows exposure-related degradation, reinforcing the viability of the recommended rehabilitation measures.

VI. CONCLUSION AND RECOMMENDATIONS

➢ *Conclusion.*

The results of the structural integrity tests indicate that while most members have not deteriorated over time, some columns, however, were constructed with poor concrete and their strengths are lower than recommended. In addition, some columns showed high corrosion potential, compromising overall safety of the structure.

➢ *Recommendations.*

It is recommended that demolition of severely weakened elements and retrofitting of partially affected members before any further construction is undertaken. These corrective actions help restore the building's structural stability, extend its service life, and ensure the safety of future occupants. Based on the test results and structural assessment findings, the following recommendations were made:

- *Demolition of Weak Members:*

Columns that exhibited low concrete strength and signs of corrosion should be demolished and reconstructed to restore full structural capacity.

- *Retrofitting Works:*

Structural members showing moderate strength or partial deterioration should undergo retrofitting using appropriate strengthening techniques. Retrofitting structural concrete columns restores or enhances their load-carrying capacity, stiffness, ductility, and durability. The aim is to avoid full demolition and reconstruction by upgrading instead.

- *Retrofitting Methods Include:*

✓ Concrete jacketing: adding reinforced concrete around the existing column to increase cross-section and confinement.
✓ Steel jacketing: encasing the column in steel plates or profiles to provide confinement and additional strength.
✓ Fibre Reinforced Polymer/Fibre Reinforced Cementitious Matrix wrapping or external reinforcement: applying fibre-reinforced polymer sheets (carbon, glass, basalt) or fibre-reinforced cementitious materials externally to improve confinement and flexural/shear performance.
✓ Hybrid methods: combining one or more of the above (e.g., concrete jacket + FRP, or steel + FRP) depending on constraints (space, access).

- *Disadvantages of Retrofitting.*

✓ Cost up-front: Some retrofits (especially advanced composites) have high material/labor cost. aseestant.ceon.rs
✓ Complexity: Existing conditions may be unknown or difficult to access; retrofitting may need temporary works.
✓ Uncertainty: Existing damage may be hidden; retrofits may not fully restore original capacity if deterioration is severe.
✓ Code/regulatory issues: older structures may not easily meet modern standards even after retrofit; sometimes retrofitting may not be sufficient for full compliance.

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