Rehabilitation Methodologies of Established Building to Embrace Repair Techniques

P. UmaSaikrishna[1], D. Pavan Kumar[2], N. Sudeep Vinay[3], E. Vaishnavi[4], M. Mukesh[5]

[1]Associate Professor, Civil Engineering, Geethanjali Institute of science and technology, SPSR Nellore.
[2]Assistant Professor, Civil Engineering, Geethanjali Institute of science and technology, SPSR Nellore.
[3,4,5]UG Students, Civil Engineering, Geethanjali Institute of science and technology, SPSR Nellore.

Abstract

Rehabilitation methodologies for established educational institution buildings, especially those exceeding 18 years of service, focus on restoring and extending structural integrity through advanced repair techniques. Over time, buildings in educational settings endure material degradation, structural distress, and evolving safety standards, necessitating comprehensive rehabilitation strategies. Common rehabilitation approaches include surface repairs to address superficial damage, such as cracks and spalling, and injection methods that fill deeper cracks and voids using epoxy or cement grouts to regain monolithic behavior and load capacity. Strengthening techniques like Fiber-Reinforced Polymers (FRP) and steel plate bonding are utilized to enhance the flexural and shear capacities of reinforced concrete elements, while external post-tensioning can counteract internal stresses and increase overall performance. Electrochemical interventions such as cathodic protection prevent corrosion of embedded reinforcement, vital for buildings susceptible to environmental exposure. For educational buildings, rehabilitation prioritizes safety, durability, and cost efficiency. Non-destructive testing (NDT) and laser scanning are increasingly adopted for precise damage assessment and effective monitoring. The integration of new materials, like self-healing concrete and nano-modified composites, represents innovative directions for repair and maintenance. Selection of techniques depends on the extent of deterioration, environmental conditions found in institutional campuses, and resource availability. Ongoing research emphasizes sustainability, aiming to reduce long-term maintenance costs and environmental footprint. These holistic methodologies ensure that aging educational buildings remain safe, functional, and capable of supporting academic activities well beyond their original design life.

Keywords: Concrete Structures, Crack Sealing, Educational Institution Building, Fiber-Reinforced Polymers (FRP), Non-Destructive Testing (NDT), Rehabilitation, Repair Techniques

1. Introduction

The rapid evolution of building technology, coupled with increasing performance requirements and environmental concerns, has elevated the importance of structural rehabilitation in modern civil engineering practice. Buildings that have been in service for extended periods frequently exhibit deterioration due to material aging, environmental exposure, changes in functional demands, and cumulative loads. Rehabilitation of such structures is not merely a corrective process but a proactive strategy to enhance safety, extend service life, optimize performance, and ensure sustainability. The Geethanjali Institute of Science and Technology**,** constructed 18 years ago, represents a typical mid-lifecycle educational facility facing accelerated wear and evolving functional requirements. Over nearly two decades of service, its structural and architectural components have been subject to environmental stresses, increased occupancy demands, and minor deformities that, if left unaddressed, may affect the overall safety and utility of the campus infrastructure. Consequently, there is a compelling need to assess the condition of the building and adopt systematic rehabilitation methodologies that can restore structural integrity while integrating contemporary repair techniques. This paper presents a comprehensive study on rehabilitation strategies tailored for the Geethanjali Institute building through detailed condition assessment, identification of deterioration mechanisms, and selection of appropriate repair technologies. Emphasis is placed on both structural and non-structural components to achieve a holistic improvement in performance. The methodologies discussed involve advanced diagnostic tools, materials science insights, and innovative repair practices that align with sustainable development principles. By examining these rehabilitation frameworks, this work aims to contribute to the broader field of structural maintenance, offering guidelines that can be adapted for other similar aging infrastructure in educational and institutional contexts.

2. Literature Review

The need for structural rehabilitation of aging reinforced concrete (RC) buildings has been increasingly emphasized in recent research due to material degradation, environmental exposure, and evolving load requirements. Contemporary studies focus not only on traditional repair methods but also on advanced composites, sustainable materials, non-destructive evaluation tools, and predictive models to enhance the durability and performance of existing infrastructure.

1. Advanced Composite Strengthening Techniques

A growing body of research highlights Fiber-Reinforced Polymer (FRP) materials as effective solutions for strengthening deteriorated RC structures due to their high strength-to-weight ratio, corrosion resistance, and adaptability. Recent reviews by Li et al. (2025) summarize current advancements, challenges, and innovations in FRP strengthening, including near-surface mounted systems and nano-enhanced adhesives for improved bond performance, highlighting their applicability across structural components such as beams, columns, and joints. Similarly, Kabashi et al. (2025) evaluate modern FRP retrofitting strategies for beam–column joints, demonstrating significant improvements in shear force capacity and displacement performance under seismic loads. The durability and mechanical behavior of FRP-reinforced concrete are further discussed in a state-of-the-art review by Ortiz et al. (2023), providing evidence of FRP effectiveness and highlighting ongoing research toward environmental resistance and long-term performance.

2. Shear and Flexural Strengthening Strategies

Abdullah & Basnet (2024) provide a comprehensive review of shear strengthening methods for RC beams, with emphasis on FRP design recommendations and application configurations to prevent brittle shear failures. A recent review in the Journal of Contemporary Technology and Applied Engineering (2025) discusses novel sustainable techniques for strengthening RC slabs, evaluating solutions for flexural and shear enhancement under various loading and environmental conditions. These studies are pivotal for understanding element-specific rehabilitation demands in buildings like educational facilities, where service loads and functional criteria evolve over time.

3. Alternative Strengthening Materials and Methods

Beyond FRP, emerging materials like Textile-Reinforced Mortar (TRM) offer promising alternatives for RC column repair. In a 2024 review, TRM is shown to be fire-resistant, cost-effective, and adaptable to various environmental conditions, making it a viable option for sustainable rehabilitation projects.

4. Comprehensive Reviews on Global Rehabilitation Practices

A 2025 journal review by Elkhatib et al. synthesizes recent global research on concrete rehabilitation techniques, emphasizing periodic structural assessment, crack mitigation strategies, and restoration practices needed to enhance durability and performance.

This comprehensive scope supports the development of rehabilitation frameworks applicable to educational buildings like the Geethanjali Institute, which require periodic evaluation and maintenance due to prolonged service life.

3. Objectives

- This study aims to evaluate the existing structural condition of the 18-year-old institutional building through detailed inspection and non-destructive testing, and to identify key deterioration mechanisms affecting its performance.
- In-situ material properties and structural adequacy of critical elements are assessed under current loading conditions. Based on the findings, appropriate repair and strengthening measures are recommended. The study further proposes a sustainable rehabilitation framework and maintenance strategy to enhance durability, safety, and long-term service life.

4. Methodology

The methodology adopted in this study follows a systematic framework for accurate condition assessment and effective rehabilitation planning of the 18-year-old institutional building. The process included preliminary data collection, detailed visual inspection, and floor-wise damage mapping to identify cracks, spalling, corrosion, dampness, and other deterioration mechanisms. Non-destructive tests such as rebound hammer, UPV, half-cell potential, and carbonation depth tests were conducted to evaluate in-situ concrete quality and corrosion probability. Microstructural analysis using SEM was performed on selected samples to study C–S–H morphology, pore structure, microcracks, and carbonation effects. Limited destructive testing and structural analysis were carried out to assess residual load-carrying capacity and safety. Based on the severity of damage, rehabilitation measures including epoxy crack injection, patch repair, corrosion protection, jacketing, and FRP strengthening were recommended. A preventive maintenance plan was also developed to enhance durability and extend the service life of the structure.

4.1. Inspection of Existing Building

The building selected for investigation forms part of the Geethanjali Institute of Science and Technology (GIST), established in 2008 in the S.P.S.R. Nellore district of Andhra Pradesh, India. Located along the Nellore–Bombay Highway at Gangavaram (V), Kovur (Mandal), the campus is situated within a coastal plain climatic zone characterized by elevated seasonal humidity, significant monsoonal precipitation, and moderate to high temperature variations. Such environmental conditions are known to influence long-term material performance, particularly in reinforced concrete structures, by accelerating processes such as moisture ingress, carbonation, and reinforcement corrosion. Over its 18-year service life, the institutional building has experienced functional adaptations, fluctuations in occupancy loads, and periodic maintenance interventions. These factors, combined with environmental exposure, contribute to progressive aging and potential structural degradation. Accordingly, the investigation commenced with a comprehensive preliminary inspection to evaluate the structural configuration, construction methodology, service history, and exposure conditions. Original structural drawings, design calculations, and material specifications were systematically reviewed to identify the load-resisting system, foundation type, reinforcement detailing, and overall structural framework. This foundational assessment established the basis for subsequent detailed evaluation and rehabilitation planning.

Figure 1: Institution Building and Plan

4.2. Visual Inspection

A comprehensive visual inspection was conducted to evaluate the extent and nature of structural and non-structural distress in the reinforced concrete building. The assessment focused on crack characteristics (length, width, orientation), surface deterioration, spalling, and signs of moisture ingress. Crack dimensions were measured using a crack width gauge and measuring tape, and photographic documentation was performed for condition mapping.

4.3. Micro Structure Analysis

Microstructural investigation was conducted to evaluate the deterioration mechanisms in the concrete samples extracted from distressed regions. Scanning Electron Microscopy (SEM) was used to examine morphological features, while Energy Dispersive X-ray Spectroscopy (EDS) was employed to determine elemental composition. The objective was to correlate observed macro-level damage (cracks, spalling, efflorescence) with micro-level degradation processes.

4.3.1. SEM Analysis

SEM analysis revealed interconnected microcracks along the ITZ, increased porosity, and voids indicating moisture-induced permeability. Partial dissolution of calcium hydroxide confirmed carbonation, while fragmented C–S–H gel suggested matrix weakening. Needle-like ettringite deposits indicated possible sulfate attack. These microstructural changes collectively explain macro-level cracking, spalling, and progressive durability deterioration.

4.3.2. EDS

EDS analysis identified major elements including Ca, Si, O, Al, Fe, and C. A reduced Ca/Si ratio indicated decalcification of C–S–H due to carbonation or leaching. Elevated carbon confirmed $CaCO_3$ formation, lowering alkalinity. Trace chloride and sulfur suggested chloride ingress and sulfate attack, contributing to corrosion and expansive deterioration mechanisms.

5. Retrieve Data from Methodology

5.1. Visual Inspection Analysis

Detailed visual inspection and crack mapping revealed significant structural and durability-related distress within the building. A major diagonal crack measuring approximately 1.2 m in length with a maximum width of 18 mm was observed at the interior corner, accompanied by localized spalling (25 cm × 15 cm), indicating severe structural movement likely due to differential settlement or stress concentration at the re-entrant corner. In the parapet wall, a 45 cm horizontal crack (3–5 mm wide) and vertical cracks (1–2 mm) were recorded, suggesting thermal and shrinkage effects. Associated spalling, water staining, and efflorescence confirm active moisture ingress and progressive durability deterioration.

Figure 2: Visual Crack Inspection analysis

Table 1: Condensed Condition Assessment

Location	Distress Type	Dimensions	Severity	Probable Cause	Recommended Action
Interior corner junction	Diagonal crack	L ≈ 1.2 m; W ≈ 18 mm	Severe	Differential settlement / structural movement	Structural evaluation; epoxy injection; crack stitching
Interior corner	Spalling	25 cm × 15 cm	Moderate–Severe	Stress concentration; loss of bond	Remove loose material; polymer-modified repair mortar

Location	Distress Type	Dimensions	Severity	Probable Cause	Recommended Action
Interior corner junction	Diagonal crack	L ≈ 1.2 m; W ≈ 18 mm	Severe	Differential settlement / structural movement	Structural evaluation; epoxy injection; crack stitching
Parapet wall (top)	Horizontal crack	L ≈ 45 cm; W 3–5 mm	Moderate	Thermal/shrinkage movement	Crack sealing; waterproofing
Parapet wall (face)	Vertical crack	W 1–2 mm	Minor–Moderate	Shrinkage strain	Surface crack filler; monitor
Parapet wall	Efflorescence & spalling	~15 sq.cm	Durability concern	Moisture ingress	Patch repair; improve drainage & waterproofing

5.2. SEM & EDS Analysis

The SEM micrograph obtained at 15.0 kx magnification reveals a heterogeneous yet relatively dense cementitious matrix characterized by irregularly shaped hydration products and dispersed unreacted particles. Flaky and agglomerated formations are observed within the binder phase, indicating the development of calcium–silicate–hydrate (C–S–H) gel alongside partially reacted mineral constituents. The presence of microvoids and fine discontinuities suggests localized porosity, which may influence permeability and long-term durability. Minor microcracks visible within the matrix are likely associated with shrinkage stresses or interfacial incompatibility between hydration products and residual particles. The corresponding EDS elemental mapping confirms the dominance of O, Si, Al, and Ca, supporting the formation of calcium aluminosilicate hydration phases. Uniform elemental distribution indicates adequate mixing and chemical integration, while trace amounts of Fe, Mg, Na, and Zn suggest minor impurities or supplementary material contributions. Overall, the microstructural features demonstrate a reasonably compact matrix with limited defects, though localized porosity may marginally affect mechanical and durability performance.

Figure 3: SEM and EDS analysis of Deteriorated Concrete

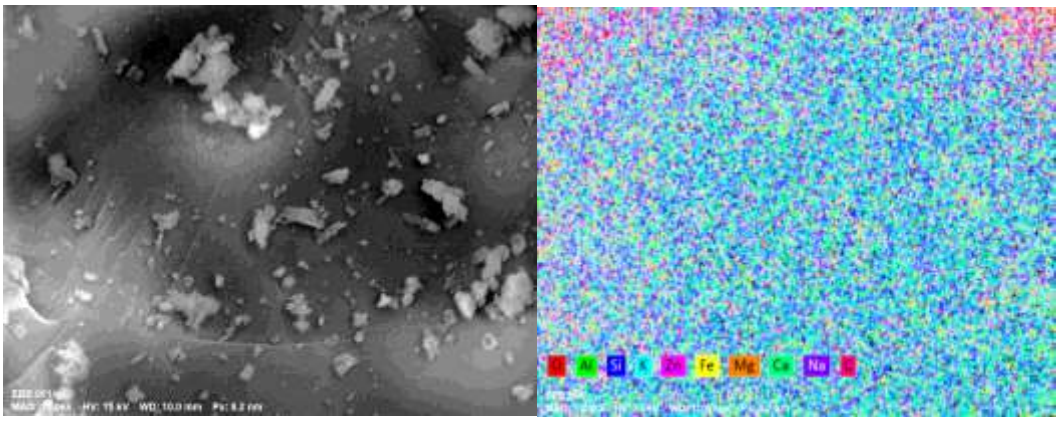
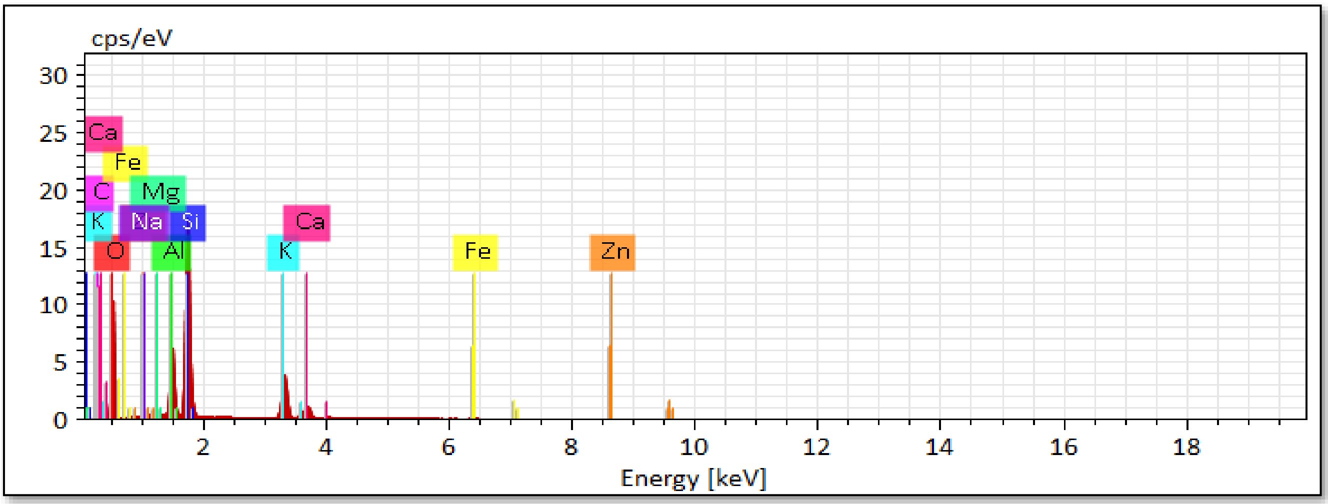


Figure 4: chemical Composition of deteriorated Concrete EDS Graph



The EDS Graph represents the presence of calcium-rich hydration products such as C–S–H and possibly $Ca(OH)_2$. The Si and Al peaks indicate the formation of aluminosilicate gel phases. Minor Mg, Na, and K peaks suggest alkali and supplementary mineral constituents, while Fe signals likely arise from trace impurities. The distinct Zn peak reflects zinc-bearing compounds, possibly from admixtures or contamination. Overall, the spectrum shows uniform elemental distribution without abnormal high-intensity peaks, indicating chemical stability within the analyzed region.

5.3. Crack Repair

Crack injection treatment was executed at the wall–window junction where diagonal structural cracks were observed. The crack line was mechanically cleaned using a wire brush and compressed air to remove dust, debris, and weak mortar particles. Surface moisture was checked prior to application. Injection nipples/ports were installed at regular intervals (approximately 150–300 mm c/c depending on crack width), and the exposed crack surface was sealed using epoxy putty to ensure pressure retention.

A low-viscosity structural epoxy resin was injected under controlled pressure using a manual injection gun, starting from the lowest port and progressing upward to ensure complete penetration. Injection at each port was continued until material refusal or visible flow from the adjacent port confirmed full crack saturation. After initial setting, the ports were removed and the surface was ground and finished. The injection process restored structural integrity, improved load transfer across the crack plane, and prevented further ingress of moisture and contaminants.

Figure 5: Crack repair works

6. Conclusions

The detailed visual inspection, crack mapping, and microstructural evaluation confirm that the 18-year-old institutional building exhibits both structural and durability-related distress.

- The major diagonal crack at the re-entrant interior corner indicates localized structural movement, likely due to differential settlement and stress concentration. Parapet wall cracks, efflorescence, and spalling further demonstrate the effects of thermal movement, shrinkage, and prolonged moisture ingress.
- SEM and EDS analysis revealed a relatively dense cementitious matrix with normal hydration products (C–S–H and aluminosilicate phases), indicating that the inherent material quality remains reasonably stable. However, localized porosity and microcracking suggest progressive durability concerns, primarily influenced by environmental exposure and moisture penetration rather than fundamental material failure.
- Considering the building's 18-year service life, the observed deterioration is within the expected performance range for institutional structures subjected to environmental and loading variations. The executed epoxy crack injection and patch repair measures are technically appropriate for restoring structural continuity and limiting further ingress of water and contaminants.

Future Planning and Recommendations

1. Periodic structural health monitoring should be implemented, particularly at re-entrant corners and parapet locations.
2. Comprehensive terrace and parapet waterproofing renewal is recommended to enhance durability.
3. Drainage detailing improvements should be incorporated to minimize moisture retention.
4. A preventive maintenance schedule (every 3–5 years) should be adopted for institutional infrastructure.
5. Full structural replacement is not immediately required; however, major rehabilitation planning may be considered after 25–30 years of service life depending on future condition assessments.

Overall, with timely maintenance and localized structural repairs, the building can continue to function safely and effectively without immediate replacement, ensuring extended serviceability and performance.

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References

1. Li, M., Du, Y., & Li, M. (2025). Review on FRP strengthened concrete structures: Current advances, challenges and emerging innovations. Global Letters in Engineering & Technology. DOI: *https://doi.org/10.54254/2755-2721/2025.GL24467*
2. Kabashi, N., Muhaxheri, M., Krasniqi, E., Murati, Y., & Latifi, F. (2025). Advancements in FRP retrofitting techniques for seismic resilience of RC structures. *Buildings*, 15(4), 587. DOI: *10.3390/buildings15040587*
3. Ortiz, J. D., Khedmatgozar Dolati, S. S., Malla, P., Nanni, A., & Mehrabi, A. (2023). FRP-reinforced/strengthened concrete: State-of-the-art review on durability and mechanical effects.

Materials, 16(5), 1990. DOI: *10.3390/ma16051990*
4. Abdullah, W., & Basnet, A. (2024). Shear strengthening and rehabilitation of normal RC beams: A review. *Emerging Technologies and Engineering Journal*.
5. Comparative analysis of novel sustainable strengthening techniques for RC slabs: A review of novel technologies (2025). *Journal of Contemporary Technology and Applied Engineering*.
6. A state-of-the-art review of TRM for repair and strengthening of reinforced concrete columns (2024). *Innovative Structures and Construction*. The reference in *Structures* (Volume 65, 2024) on TRM strengthening has DOI: *10.1016/j.istruc.2024.106739*
7. Elkhatib, L., Khatib, J., Fırat, S., El Hassan, H., & Elkordi, A. (2025). Rehabilitation of concrete structures: A comprehensive review. *Gazi University Journal of Science*, 38(2), 665–685.