RADemics

AI-Assisted Material Strength Evaluation and Structural Health Monitoring of Buildings

Chetan S. Chavan, Debabrata Das
PCET's Pimpri Chinchwad College of Engineering and Research, Dr. Sudhir Chandra Sur Institute of Technology and Sports Complex

AI-Assisted Material Strength Evaluation and Structural Health Monitoring of Buildings

[1]Chetan S. Chavan, Assistant Professor, Department of Civil Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, Maharashtra, India. chetanchavan1203@gmail.com

[2]Debabrata Das, Assistant Professor, Mechanical Engineering Department, Dr. Sudhir Chandra Sur Institute of Technology and Sports Complex, Kolkata, West Bengal, India, debabrata.das@dsec.ac.in

Abstract

The performance, durability, and safety of modern buildings are inherently dependent on the mechanical properties of construction materials and the continuous assessment of structural health. Traditional material evaluation and monitoring approaches are limited in scalability, real-time assessment, and predictive capability, creating challenges for high-rise and complex urban structures. Artificial intelligence (AI) has emerged as a transformative solution, enabling predictive modeling of material strength, anomaly detection, and proactive structural health monitoring (SHM) through integration with advanced sensing networks and digital infrastructure. This chapter presents a comprehensive overview of AI-assisted material strength evaluation and SHM, highlighting machine learning and deep learning techniques for predicting concrete, steel, and composite behavior under operational and environmental stresses. Case studies of high-rise buildings demonstrate successful deployment of multi-sensor networks, digital twins, and Building Information Modeling (BIM) for real-time monitoring, predictive maintenance, and lifecycle optimization. The integration of AI with smart building systems facilitates data-driven decision-making, enhances safety standards, and promotes sustainable construction practices by minimizing resource-intensive repairs and prolonging structural service life. Emerging trends, including explainable AI, hybrid predictive models, and IoT-enabled infrastructures, offer opportunities for improved reliability and operational efficiency in building management. The insights presented in this chapter provide a framework for researchers, engineers, and practitioners to implement intelligent, proactive, and resilient material and structural assessment strategies in contemporary urban environments.

Keywords: Artificial Intelligence, Material Strength Evaluation, Structural Health Monitoring, High-Rise Buildings, Digital Twin, Predictive Maintenance.

Introduction

The structural integrity and longevity of modern buildings are fundamentally dependent on the mechanical properties of construction materials [1]. Materials such as concrete, steel, timber, and advanced composites must endure a wide range of static and dynamic loads while maintaining resilience under environmental stresses including wind, seismic forces, and thermal fluctuations [2]. Material strength directly affects safety, serviceability, and overall performance, making accurate evaluation an essential component of structural engineering. Conventional laboratorybased tests, such as compressive, tensile, and flexural evaluations, provide precise measurements under controlled conditions [3]. These tests, while reliable for initial design verification, are limited in capturing material behavior in real operational conditions, especially in large-scale or high-rise structures. Non-destructive techniques, including ultrasonic pulse velocity, rebound hammer tests, and radiographic inspections, enable field-based evaluation but often provide only localized or partial insights into structural performance [4]. Heterogeneity in material composition, construction quality, and environmental exposure introduces variability in results, highlighting the need for continuous monitoring methods that can evaluate materials under actual service conditions. The combination of accurate material characterization and structural analysis forms the foundation for safety, sustainability, and cost-effective building management, creating a critical need for advanced approaches that overcome the limitations of conventional evaluation techniques [5].

Structural health monitoring (SHM) has emerged as a vital technology for maintaining building performance throughout its lifecycle [6]. By integrating sensors, data acquisition systems, and analytical frameworks, SHM enables continuous tracking of structural responses under operational loads, environmental effects, and aging-induced material degradation [7]. Traditional inspection methods, relying on periodic visual checks or manual measurements, often fail to detect early-stage structural anomalies, resulting in delayed interventions and higher maintenance costs. Advanced SHM systems employ vibration-based measurements, acoustic emission sensing, strain monitoring, and thermal imaging to provide detailed insight into stress distribution, crack propagation, and localized deterioration [8]. These systems generate large volumes of heterogeneous data, necessitating advanced computational approaches for effective interpretation. Multi-sensor data fusion enhances assessment accuracy by correlating information from diverse sources, allowing comprehensive evaluation of structural performance across large buildings. Real-time monitoring facilitates proactive maintenance strategies by identifying potential failures before critical thresholds are reached [9]. The integration of SHM with predictive models ensures timely decision-making, reduces operational risks, and improves the overall resilience of structures. Such capabilities position SHM as a critical component for intelligent urban infrastructure management, bridging the gap between traditional inspection methods and predictive, data-driven maintenance strategies [10].