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Initial Investigation of Fire-Damaged Reinforced Concrete Structures Using Visual Inspection

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ABSTRACT: Fire incidents can cause significant degradation to structural elements, compromising the load-bearing capacity and overall safety of buildings. After such events, rapid and accurate structural integrity assessment is essential to support technical decision-making. This study uses visual inspection as the primary method to evaluate the damage level of reinforced concrete structures in the Faculty of Engineering at Universitas Negeri Makassar following a fire incident. The investigation was conducted through direct observation of key structural elements, namely columns, slabs, and beams, and damage was classified into four categories: undamaged, light, moderate, and severe. The results indicate that the most significant damage occurred on the first floor, with 33.8% of columns and 33.4% of slabs showing severe damage. In contrast, the second and third floors remained largely intact, suggesting that the fire's highest intensity was concentrated at the ground level. Visual inspection provided an initial overview of structural conditions and identified critical areas for further evaluation. This study highlights the importance of visual inspection as an initial tool in post-fire structural assessment and forms a basis for subsequent testing and rehabilitation planning.

KEYWORDS: visual inspection, fire-damaged buildings, structural evaluation, reinforced concrete, damage classification

I. INTRODUCTION

Buildings are critical infrastructure that must ensure the safety and functionality of their occupants. However, fire hazards significantly threaten structural integrity, potentially leading to severe damage and failure of essential load-bearing components. Fires can alter construction materials' physical and mechanical properties, especially reinforced concrete, resulting in surface cracking, spalling, loss of bond between concrete and reinforcement, and permanent deformation. Consequently, assessing the condition of fire-damaged structures is essential before any decision is made regarding continued use, rehabilitation, or demolition.

Various assessment techniques have been developed to evaluate structural damage, ranging from traditional engineering judgment to advanced structural health monitoring (SHM) systems. This system is an innovation that has received a lot of attention from researchers as a solution to ensure structural safety (1–3). (4) proposed a shear deformation-based non-destructive evaluation (NDE) method, emphasizing its significance for aging reinforced concrete beams. Emerging technologies, such as convolutional neural networks (CNN) for damage detection (5) and Bayesian updating techniques for adaptive structural modeling (6–8) have further enhanced the precision and responsiveness of damage assessment. Metaheuristic algorithms, like the shrimp-goby cooperative algorithm presented by (9), demonstrate how optimization can be applied in complex structural diagnostics. (10) further reinforced this shift by presenting a comprehensive review of recent advancements in damage identification methods, noting how technological progress is continuously reshaping structural diagnostic paradigms.

Despite these advancements, visual inspection remains a fundamental and widely used method in the early stage of structural assessment, especially for post-fire scenarios. It is valued for its speed, cost-effectiveness, and ability to provide immediate insights without altering the structural elements. (11). (12) extended the application of visual-based techniques to the analysis of carbon fiber composites, illustrating the method's adaptability across engineering disciplines.

In the context of post-fire structural evaluation, visual inspection plays a crucial role. (13) showed how color changes in coatings and materials could be used to assess heat exposure on steel bridges. Similarly, (14) emphasized the importance of immediate visual assessments following fire events in industrial buildings to prevent further hazards. However, (15) cautioned that the accuracy of such inspections depends heavily on the inspector's experience, recommending integration with thermographic and non-destructive technologies to improve reliability.

Recent developments in damage classification based on visual data have also emerged. (16,17) utilized machine learning and aerial imagery to classify post-disaster damage levels, while (18) proposed a hybrid method combining UAV data and manual inspection for enhanced accuracy. (19) contributed by developing fragility curves to rapidly estimate structural vulnerability based on typology and visual indicators.

Beyond engineering, (20) demonstrated the use of visual investigation in ethnographic contexts to interpret community perceptions of cultural heritage objects, highlighting the method's cross-disciplinary relevance. In a more technical setting, (12)applied visualization-based techniques combined with eddy current measurements to examine the internal structure of carbon fiber composites, reinforcing the broader applicability of visual inspection in non-destructive evaluations.

Nevertheless, there remains a lack of case studies applying visual inspection methods to fire-damaged educational buildings in Indonesia, which have distinct construction types and usage patterns. Local variables—such as construction practices, building age, and maintenance history—significantly influence the extent and pattern of fire-induced damage.

This study aims to address this gap by conducting an initial investigation of structural damage through visual inspection of a reinforced concrete educational building affected by fire. The focus is on evaluating the condition of columns, slabs, and beams across three floors of the structure. The findings of this study are expected to offer practical insights into post-fire structural diagnostics and serve as a reference for further technical evaluation and rehabilitation planning.

II. RESEARCH METHOD

This study adopts a descriptive forensic approach to assess the structural condition of a reinforced concrete building affected by fire. It represents the initial stage of a broader investigation into the post-fire performance of the Faculty of Engineering building at Universitas Negeri Makassar. The primary objective of this phase is to perform a visual-based assessment of damage distribution and severity across major structural elements.

The object of study is a three-story reinforced concrete building located within the university's engineering faculty complex. The fire incident caused varying degrees of visible damage, prompting the need for an immediate condition assessment. The focus of the investigation includes structural columns, floor slabs, and beams on all three building floors. The inspection was conducted in situ and systematically covered all accessible structure parts to ensure a comprehensive and representative evaluation.

Data collection relied exclusively on visual inspection techniques. Observations were made through direct on-site examination to identify physical signs of damage typically associated with fire exposure. These signs include surface discoloration, indicative of thermal effects; cracking, ranging from hairline to structural; delamination or peeling of plaster; concrete spalling; exposed reinforcement; and signs of permanent deformation such as deflection or swelling of structural members. All observed damage was documented in field notes, digital photographs, and annotated floor plans to represent damage distribution spatially.

To interpret the findings, damage severity was categorized into four levels: undamaged, light, moderate, and severe. This classification was based on recognized criteria commonly used in post-disaster assessments, such as visual changes in surface condition, crack patterns, exposure of internal reinforcement, and signs of structural compromise. The categorization facilitated the quantification of damage across different floors and elements and served as a basis for mapping critical zones requiring further investigation in subsequent research phases.

III. RESULTS AND DISCUSSION

A. Results

Condition of Columns

The visual inspection of structural columns revealed significant damage concentration on the first floor (Figure 1). Of the 77 columns observed, 33.8% were classified as severely damaged. These columns exhibited clear signs of concrete spalling, structural cracking, detachment of plaster layers, and exposed reinforcement, suggesting a considerable loss of load-bearing capacity. Another 5.2% of columns experienced moderate damage, while 19.5% were categorized as lightly damaged. Only 9% of the columns remained in undamaged condition. This distribution suggests that the first floor was likely the primary location of the fire's origin or experienced the highest heat intensity.

On the second floor (Figure 2), 96% of columns were in good condition, with only 4% showing signs of severe damage, such as exposed steel and brittle concrete response upon percussion. The third floor showed minimal damage (Figure 3), where 98.4% of columns were classified as undamaged and only one column exhibited severe damage characterized by bulging and significant cracking. These findings indicate that the vertical spread of the fire diminished significantly on higher floors, likely due to fire containment or the thermal gradient effect.

Figure 1. Severe Spalling and Cracking on First-Floor Column

Figure 2. Vertical Cracking on Second-Floor Column

Figure 3. Minor Hairline Crack on Third-Floor Column

Condition of Slabs

The floor slabs on the first level (Figure 4) showed substantial signs of fire-related deterioration. Of 51 observed slabs, 33.4% were severely damaged, with visible signs such as concrete crushing, reinforcement rupture, and detachment of the steel bars from the concrete matrix. Moderate damage was observed in 7.8% of the slabs, and 58.8% remained in satisfactory condition. The severity and nature of the slab damage suggest that structural performance under gravity loads would be compromised without proper rehabilitation.

Figure 4. Severe Concrete Spalling and Reinforcement Exposure on First-Floor Slab

The damage was significantly less extensive on the second floor (Figure 5). Approximately 89.1% of the slabs were undamaged, 2.2% were moderately damaged, and only 8.7% exhibited severe visual defects. These results are consistent with the findings in the column assessment, reinforcing the conclusion that fire intensity was most critical at the ground level.

Figure 5. Localized Concrete Loss and Reinforcement Exposure on Second-Floor Slab

Condition of Beams

Beams were generally the least affected among all structural elements, particularly on the upper floors. On the first floor (Figure 6), out of 116 beams inspected, 7.8% showed signs of severe damage, primarily in cracking and deflection. Only 1.7% experienced moderate damage, while 90.5% were in good condition. The second floor (Figure 7) exhibited even better performance, with 95.7% of beams undamaged, 2.6% severely damaged, and 1.7% moderately affected.

Figure 6. Extensive Spalling and Reinforcement Exposure on First-Floor Beam

Figure 7. Cracking and Minor Concrete Loss on Second-Floor Beam

This damage pattern reflects the relative protection of beams due to their location within the structural system, often shielded by slabs or other architectural elements. Nonetheless, damaged beams directly above deteriorated columns or slabs may still be structurally compromised and require further analysis.

B. Discussion

Severity of Structural Damage on the First Floor

The visual inspection results reveal that the first floor sustained the most significant structural damage, particularly to columns and slabs. The high percentage of severely damaged columns (33.8%) suggests a high degree of thermal exposure, consistent with findings by (13), who reported that intense fire exposure often leads to surface spalling, cracking, and reinforcement exposure in concrete structures. These characteristics indicate a loss of compressive strength and bond integrity between concrete and steel reinforcement, which can critically affect vertical load-bearing capacity and increase the potential for progressive collapse.

Damage Patterns in Slabs and Beams

The floor slabs on the first level also showed severe deterioration, such as ruptured reinforcement and concrete disintegration. Similar degradation patterns were reported by (14), who emphasized that post-fire inspection should focus on critical elements such as slabs and floor diaphragms due to their role in lateral load distribution and occupant safety. In contrast, the beam elements exhibited better resistance to visible damage, possibly due to their more protected positions and cross-sectional mass. Post-fire damage patterns, particularly spalling and punching shear failures, are significantly influenced by the fire scenario and reinforcement configuration. This highlights the need for detailed visual inspections to identify critical zones that might have lost bearing capacity due to thermal degradation (21). Visible crack propagation and material surface deterioration—when observed consistently during post-damage evaluations—can serve as early indicators of fatigue and durability decline, especially under combined environmental and loading effects (22).

Vertical Gradient of Fire Impact

Visual inspection in this study proved to be an effective preliminary method for identifying damage concentration and classifying severity. While visual inspection is limited in providing quantitative data, it is essential for early-stage decision-making and prioritizing areas for further evaluation (11,15). Nevertheless, the accuracy of this method can be highly dependent on the inspector's experience and the clarity of classification criteria. Hence, to strengthen the findings, integration with non-destructive testing (NDT) techniques—such as rebound hammer, ultrasonic pulse velocity (UPV), and core drilling—is recommended in subsequent stages (23,24).

These visual findings, while preliminary, serve as a reliable basis for selecting critical structural zones for advanced testing and modeling. They also contribute to the ongoing refinement of damage classification frameworks for fire-damaged reinforced concrete buildings in tropical climates, which remain underrepresented in current literature (19). Visual and instrumental inspection methods play a critical role in the post-disaster evaluation of reinforced concrete structures, particularly in identifying surface-level damage that guides further assessment (25). Visual inspection, as applied in explosion testing of concrete elements, is instrumental in recording initial damage symptoms, particularly spalling and cracking patterns prior to detailed laboratory analysis (26).

V. CONCLUSIONS

1. The visual inspection conducted in this study successfully identified the distribution and severity of structural damage in a fire-affected reinforced concrete building. The most critical deterioration was observed on the first floor, where 33.8% of columns and 33.4% of slabs exhibited severe damage such as spalling, cracking, and exposed reinforcement. In contrast, the second and third floors showed minimal levels of damage, indicating a downward concentration of fire intensity.
2. Visual inspection has proven to be an effective and rapid preliminary method for post-fire damage assessment. While it does not provide quantitative data on material strength, it enables practical identification of critical areas requiring further evaluation. This approach aligns with previous findings and reinforces its role as a foundational step in post-disaster structural diagnostics.
3. The findings from this initial investigation provide a basis for future assessment stages involving non-destructive testing and structural analysis. These subsequent methods will be essential for determining residual capacity and planning appropriate rehabilitation measures for the affected elements. This study contributes to the broader understanding of fire-induced structural damage in educational facilities, particularly in tropical environments.

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