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Structural Assessment Material and Fire Induced Strength Degradation Material of Multistory Building

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Abstract
This paper presents a detailed case study of a multistory building near Bombay Motors in Jodhpur that suffered severe fire damage, with temperatures reaching up to 900°C. The fire brigade arrived 30 minutes after the incident. Under the guidance of MBM University, research scholars conducted site investigations to analyze the impact of the fire on the building's materials, particularly concrete and reinforcement. The study reveals how the fire weakened these materials, leading to a significant reduction in the building's strength, especially in the columns. Notably, Floor 4 retained more strength than Floor 3, with strength differences ranging from +26.67% in one column to -20% in another. This highlights the variation in damage, indicating that while some columns on Floor 4 remained stronger, others experienced considerable strength loss. The findings emphasize the vulnerabilities exposed by fire and suggest ways to enhance building resilience. The research advocates for updates to building codes to incorporate better fire safety measures and provides valuable insights for improving firefighting and evacuation plans during emergencies. While the study is focused on this particular building, its results can also inform urban planning and fire risk management in other high-risk areas. By identifying weaknesses in design and materials, the study offers guidance for architects, engineers, and policymakers. Overall, the case study contributes to the goal of creating safer, stronger buildings in similar environments, promoting better construction practices and fostering safer cities. Additionally, the evaluation of residual strength was conducted using ISO 834 and Euro Code standards, and simulations performed through Abaqus software yielded results closely aligned with experimental techniques.

1. Introduction

The research articles offer valuable insights into how fire impacts concrete buildings, focusing on two key areas: the structure's strength and how its ability to support weight decreases when exposed to high temperatures. The studies reveal that concrete loses much of its strength under heat, though higher-grade concrete shows better resistance. In this case, the fire was caused by a short circuit, and the fire brigade arrived 30 minutes after the incident. A fire safety team from MBM University, Jodhpur, India, supervised the investigation, with research scholars collecting data using colorimetry to measure the temperature and evaluate the building's remaining strength. [1]. Moreover, a novel fire damage assessment framework proposed for reinforced concrete tunnel linings seamlessly integrate cutting-edge modeling techniques. This framework facilitates the quantification of damage metrics such as surface discoloration, crack width, and strength loss, thus streamlining the process of postfire repairs [2]. Furthermore, the research accentuates the critical importance of assessing concrete's mechanical properties following exposure to fire. Notably, there's a significant decline in strength, particularly pronounced in higher grade concretes, with tensile and flexural strengths bearing the brunt of the impact compared to compressive strength [3].

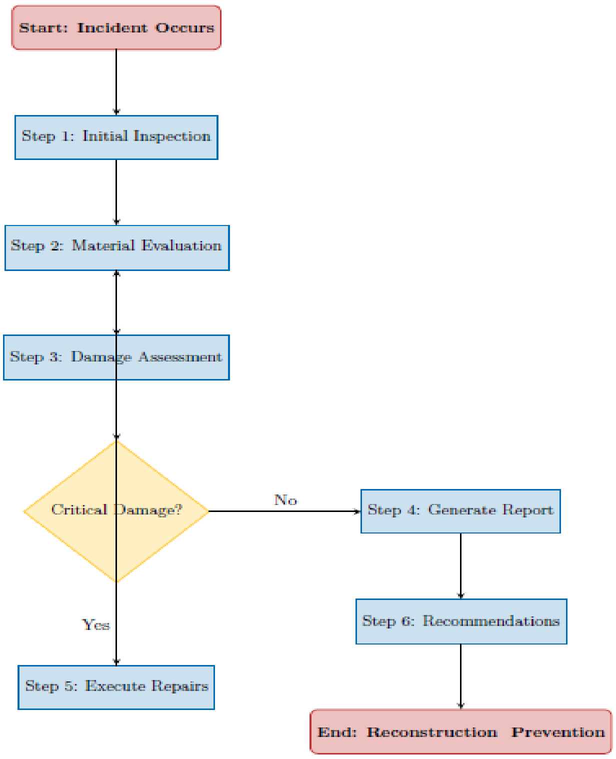

Figure 1 Flow Chart

Natural fiber composites, such as sisal, coconut, jute, henequen, and esparto, are increasingly finding applications across various engineering domains [4]. These composites boast mechanical characteristics influenced by factors such as specific gravity, length, diameter, and processing methods, thereby broadening their utility from automotive to biomedical sectors. The incorporation of natural fibers not only enhances environmental sustainability and cost-effectiveness but also fosters innovation in construction practices, in line with principles of sustainability and environmental stewardship [5]. Furthermore, lesser-known fibers like henequen and esparto demonstrate promising attributes, including thermal resistance and mechanical properties comparable to widely used fibers like bamboo and hemp [6]. Based on the Figure 1, flowchart, the research paper's overview becomes clear, illustrating each step that was carried out in the study.

2. Literature Review

The deterioration of concrete strength due to fire at elevated temperatures profoundly affects the structural integrity of buildings [7], [8]. It is imperative to conduct research on the residual mechanical properties following fire exposure to accurately evaluate structural strength [9]. Investigations into concrete strength under fire conditions indicate a decline in compressive strength, with higher grade concrete demonstrating superior resistance to elevated temperatures [10]. Studies analyzing the impact of fire on reinforced concrete structures reveal a significant decrease in both load resistance and deformation capacity with prolonged exposure to fire [11]. Additionally, a study focusing on bond behavior in reinforced concrete members postfire emphasizes the critical importance of assessing residual bond strength to ensure structural safety in the aftermath of a fire. Understanding the mechanisms underlying structural degradation and resilience in fire conditions is essential for the design of more resilient buildings. At the time of the fire, the media captured images of the building, which are presented in Figure 2.

Figure 2 External View of Building during Firing Timing

Figure 3 External View of Post Fire Building

The building's columns, particularly in C5, C6, and C4, incurred the majority of losses primarily due to extensive fire damage, as visually assessed [12]. The duration of the fire directly correlated with the temperature reached, notably impacting the third and fifth floors, which bore direct harm from the flames [13]. Fire safety engineering principles underscore the crucial importance of comprehending the effects of fire to mitigate casualties and property damage [14]. Studies on structural behavior under fire induced progressive collapse scenarios reveal a significant decrease in load resistance when the fire duration exceeds 30 minutes, with critical failure points identified based on the duration of the fire [15]. The implementation of a systematic evacuation system, tailored to the building's characteristics, can effectively minimize casualties in fire incidents, underscoring the significance of establishing appropriate evacuation routes for swift and safe evacuation [16]. Figure 3 shows External View of Post Fire Building. Figure 4 shows Plan for the Second and Third Floors

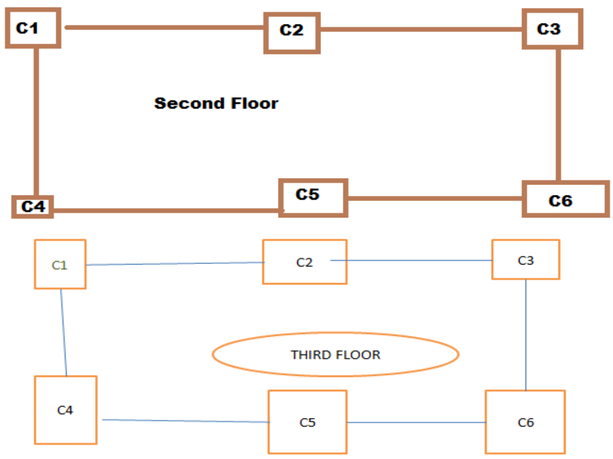

Figure 4 Plan for the Second and Third Floors

3. Assessment of Damaged Building

3.1 Assessment of fired column

The damage observed on the columns following the fire aligns closely wit Exposure to fire significantly diminishes the loadbearing capacity of columns, and longer exposure durations exacerbate this effect [17]. Furthermore, fire damage can impair both the axial and lateral load capacities of columns, influencing their stiffness, ductility, and energy dissipation established research findings concerning the impact of fire on reinforced concrete (RC) columns. damage can impair both the axial and lateral load capacities of columns, influencing their stiffness, ductility, and energy dissipation abilities [18]. After exposure to fire, the residual compressive strength of RC columns is notably decreased, with the degree of damage influenced by factors such as column height and applied load ratios [19]. The presence of joint failures, concrete spalling, and visible reinforcement damage in the observed columns across various floors underscores the common structural compromise observed in concrete structures postfire, highlighting the necessity for comprehensive postfire assessments [20]. Figure 5 shows External View of the Column on Floor 2.

Figure 5 External View of the Column on Floor 2

1.1 F-Refers for Floor

The figures primarily depict the condition of column 5 and subsequently showcase the condition of column 4 on floor 2. These visual representations provide a clear depiction of the structural integrity of the columns following the fire incident, offering valuable insights into the extent of damage and deterioration incurred. The primary objective of this paper was to assess the strength of columns subsequent to fire exposure. By analyzing the conditions of columns on floors 3 and 4, we aimed to elucidate the effects of fire induced damage on structural elements and inform strategy for structural repair and reinforcement. Figure 6 shows Column 1 to Column 5 and Figure 7 shows Condition of The Column on Floor 4

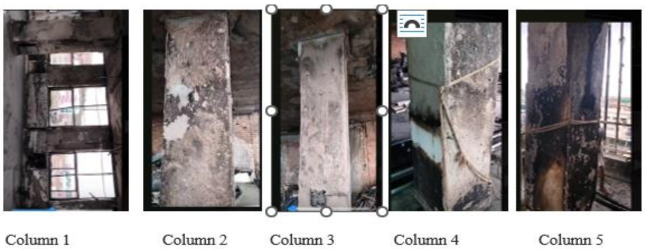

Figure 6 Column 1 to Column 5

Figure 7 Condition of The Column on Floor 4

The ISO 834 and ASTM E119 standards are essential for globally standardized fire resistance testing of structural elements [21]. The ISO 834 time-temperature curve provides a fundamental benchmark, expressed, as

$$T = 345\log10\,(8t + 1) + T_O$$

T_O = Ambient Temperature (20-27 ^{O}C)

t= firing time period

Extensively used to track temperature changes over time [22], EN 1991 Parts 1 and 2 introduce two additional curves to account for hydrocarbon and external fire effects, enhancing the evaluation of structural fire resistance [23]. Furthermore, the ASTM E119 curve, specified in ASTM 2016, provides detailed insights into temperature variations experienced by fire-resistant building elements, facilitating the assessment of their performance under fire exposure [24]. These standardized curves are critical for ensuring building safety and resilience against fire incidents, offering essential guidelines for the design and evaluation of structural elements to strengthen fire protection measures. (Refer Table 1)

Table 1 Temperature Achieved According Euro Code at Particular Time Period

S. No	Temperatures	Time periods
1	538°C	At 5 min
2	704°C	at 10 min
3	843°C	at 30 min
4	927°C	at 1 h
5	1010°C	at 2 h
6	1093°C	at 4 h
7	1260°C	at 8 h or over

Various studies have tested carbonation at different temperatures and observed corresponding color changes. The carbonation reaction with carbon emissions during firing triggered a phenolphthalein reaction. The depth of carbon penetration was also evaluated through carbonation testing. During the spray process, the color change indicated the specific temperature responsible for each observed effect [25]. These alterations in color within the carbonation products serve as visual cues of the polymorphs present, facilitating temperature determination and characterization of the carbonation process. Color changes from light to dark pink, depending on the temperature, was important for checking how hot RCC structures get. Studies on materials like concrete and dental products provide important information. By studying the color of concrete, that predict fire temperatures, helping us evaluate the extent of fire damage in RCC buildings within temperature ranges of 0-300°C and 300-600°C. [26]. These color range detailed in Table 2 and Table 3 postfire building assessment. Various studies have tested carbonation at different temperatures and observed corresponding color changes. The carbonation reaction with carbon emissions during firing triggered a phenolphthalein reaction. The depth of carbon penetration was also evaluated through carbonation testing. During the spray process, the color change indicated the specific temperature responsible for each observed effect [25].

Table 2 Conditional Assessment of Floor 3

Column	Color	Approximate temperature
1		After applying phenolphthalein to the column, the center exhibited a pink/reddish hue, indicative of temperatures within the 300-600°C range.
2		The upper layer of concrete showed signs of spalling, while the lower end remained intact and safe. Upon applying phenolphthalein spray, the color change indicated an approximate temperature of 400°C..
3		The column's entire cover exhibited spalling, prompting the application of phenolphthalein spray on approximately one-third of its length from the upper end. The resulting color change to red indicated an approximate temperature of 500°C.

Table 3 Condition Assessment Column on The Floor 4

Column	Color on column	Approximate temperature
1		The reinforcement became visible due to concrete spalling, though slight soot deposition without significant color change was noted, but a light pink hue indicated exposure to elevated temperatures.
2		The partially intact column showed a light pink or reddish color with phenolphthalein spray, indicating a temperature of 500°C.
3		The phenolphthalein test showed a dark pink-reddish color, indicating an approximate temperature of 500°C.
4		The column showed severe deterioration, with a light pink color from the phenolphthalein indicating a temperature range of approximately 0–600°C.

5		The column had soot deposition, and a light pink color from phenolphthalein indicated temperatures around 300–400°C.
6		The column's external structure was damaged, showing no color change with phenolphthalein, indicating around 400°C, while soot deposition yielded a light pink color, suggesting 300–400°C.

4. Result And Discussion

4.1 Post-Fire Strength Assessment of Concrete Columns

To comprehensively assess the decrease in strength at varying temperatures and grasp the timeline of structural deterioration during a fire event, it is imperative to account for the temperature sensitive characteristics of materials [27]. Concrete exhibits markedly different residual strength levels following fire exposure, contingent upon cooling methods, with specimens cooled by water spray experiencing greater strength reduction compared to those air-cooled [28]. Following fire exposure, the mechanical attributes of concrete deteriorate, with a more pronounced decline observed in tensile and flexural strengths in contrast to compressive strength, particularly noticeable in higher grade concrete mixes [29]. Previous research has scrutinized the influence of coarse aggregate types on strength degradation in concrete under high temperatures, unveiling divergent trends compared to conventional codes and standards [30]. Employing finite element analysis to assess fire load, exposure duration, and temperature distribution facilitates a deeper comprehension of structural reactions to fire exposure, aligning with European Standard protocols. [31] According to the European code, the reduction factor employed in evaluating the residual strength of fired RCC structures is also utilized in Table 4, Table 5, and Table 6. Compressive strength reduction varies according to the temperature experienced by each column during the building's exposure to fire. The table provided above outlines the relationship between increasing temperature and the corresponding decrease in concrete strength. In a research paper, this statement could be presented as follows:

Table 4 The Temperature after Firing of Building at floor 3 and floor 4

Column	Columns Temperature °C on Floor 3	Column Temperature °C on Floor 4
C1	500	300
C2	350	500
C3	400	500
C4	500	600
C5	350	400
C6	600	400

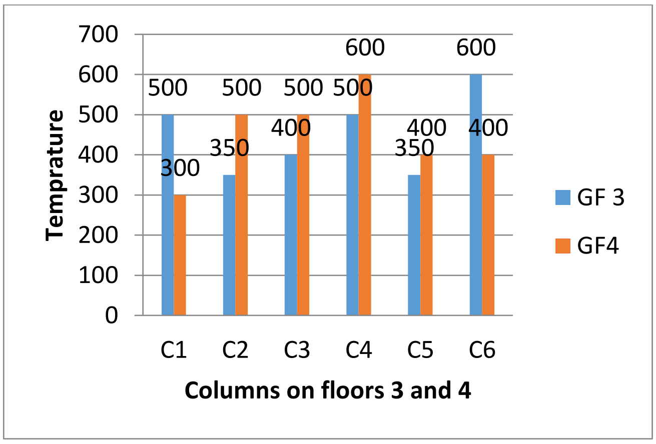

Figure 8 Temperatures on Each Column after Firing on F3 and F4

Statement could be presented as follows: Data collection from the building revealed variations in temperature across different columns on floors 3 and 4, resulting in varying strength levels. The concrete used was of grade M25 MPa, and the observed strength reduction was consistent with the specifications for this grade, decreasing with higher temperatures according to ISO 834 and Eurocode Part 2. Figure 8 shows Temperatures on Each Column after Firing on F3 and F4.

Table 5 Reduction Coefficient on Floors 3 and 4 at Various Column Temperatures Postfire Incident

Column	Temperature °C on F 3	Reduction coefficient on F 3 Kø	Temperatures °C on F4	Reduction coefficient on F 4 Kø
C1	500	66.67	300	40.00
C2	350	46.67	500	66.67
C3	400	53.33	500	66.67
C4	500	66.67	600	80.00
C5	350	46.67	400	53.33
C6	600	80.00	400	53.33

Table 6 Degradation of Strength Due To Different Temperature of Column at Different Column of F 3

Column	Temperature °C on F 3	Reduction coefficient on F 3 Kø	Grade of concrete MPa (fck)	(fck), Reduced strength in MPa (KøM25)
C1	500	66.67	30	20
C2	350	46.67	30	14
C3	400	53.33	30	15.99
C4	500	66.67	30	20
C5	350	46.67	30	14

Tables 7 Degradation of Strength Due To Different Temperature of Column at Different Column of F 4

Column	Temperatures °C on F4	Reduction coefficient on F 4 Kø	Grade of concrete MPa (fck)	(fck) Reduced strength in MPa (KøM25)
C1	300	40.00	30	12
C2	500	66.67	30	20
C3	500	66.67	30	19.99
C4	600	80.00	30	24
C5	400	53.33	30	15.99
C6	400	53.33	30	15.99

The following graph compares the strength of the columns at F 3 and F 4. It shows the strength at various columns of F 3 and F 4. Then the strength was varying on different on columns. Comparison:

- **C1:** The strength reduction is 33.33%, whereas the residual strength is 60%, resulting in a 26.67% higher residual strength.
- **C2:** The strength reduction is 53.33%, compared to a residual strength of 33.33%, showing a 20% higher reduction.
- **C3:** The strength reduction is 46.70%, while the residual strength is 33.37%, indicating a 13.33% higher reduction.
- **C4:** The strength reduction is 33.33%, and the residual strength is 20%, resulting in a 13.33% higher reduction.
- **C5:** The strength reduction is 53.33%, whereas the residual strength is 46.67%, showing a 6.66% higher reduction.
- **C6:** the strength reduction was 53.44 % whereas the residual strength 80% showing +26.56% lower reduction

4.2 Simulation Techniques

As shown in Figure 9, The same model was analyzed using Abaqus software to simulate the heat flux values and temperature for each color zone, with results closely aligning with the experimental data.

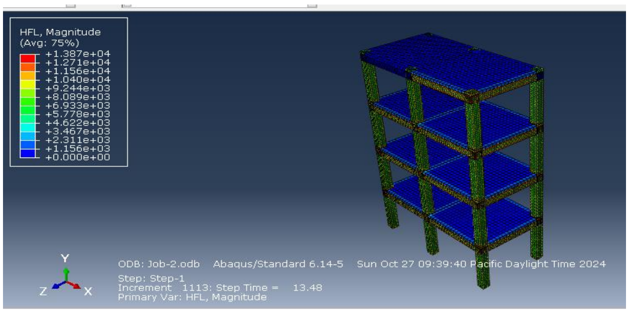

Figure 9 Heat Flux Values

Table 8 **Heat Flux, Color Codes, and Temperatures**

S. No	Heat Flux (W/m²)	Temperature Rise (°C)	Colour Code
1	1.387×104	925.00 °C	Red
2	1.271×104	847.33 °C	Orange
3	1.156×104	770.67 °C	Yellow
4	1.040×104	693.33 °C	Light Yellow
5	9.244×103	616.27 °C	Greenish Yellow
6	8.089×103	539.27 °C	Light Green
7	6.933×103	462.20 °C	Light Blue-Green
8	5.778×103	385.20 °C	Cyan
9	4.622×103	308.13 °C	Blue-Green
10	3.467×103	231.13 °C	Blue
11	2.311×103	154.07 °C	Dark Blue
12	1.156×103	77.07 °C	Darker Blue
13	0.000×100	0.00 °C	Deep Blue

Comparison:

- **C1:** 33.33% reduction vs. 60% residual (+26.67%)
- **C2:** 53.33% reduction vs. 33.33% residual (-20%)
- **C3:** 46.70% reduction vs. 33.37% residual (-13.33%)
- **C4:** 33.33% reduction vs. 20% residual (-13.33%)
- **C5:** 53.33% reduction vs. 46.67% residual (-6.66%)
- **C6:** 53.44% reduction vs.80% residual (+26.56%)

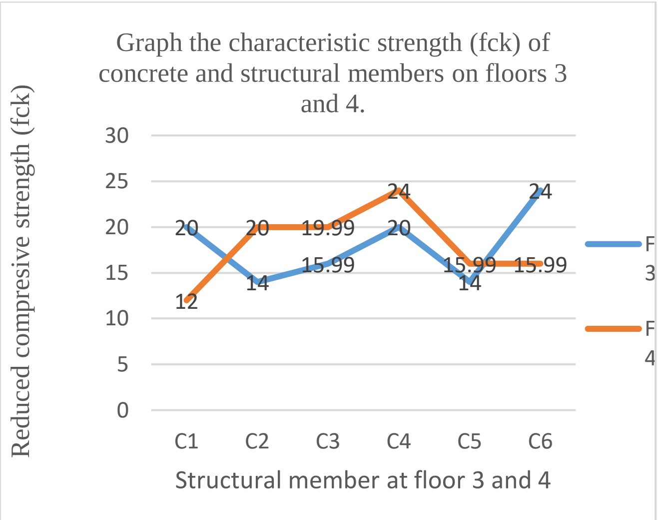

Figure 10 **Comparison of Residual Strength between Columns on Floors 3 and 4**

Overall, the residual strength on Floor 4 tends to be higher than the reduced strength on Floor 3, with varying differences across the columns. Tables 7 shows Degradation of Strength Due To Different Temperature of Column at Different Column of F 4. Table 8 shows Heat Flux, Color Codes, and Temperatures

Conclusions

The analysis of strength reduction and residual strength across the columns reveals significant insights into the structural performance under fire exposure. C1 and C6 demonstrate notable resilience, maintaining higher residual strengths (60% and 80%, respectively) despite experiencing reductions of 33.33% and 53.44%. This indicates effective performance in withstanding thermal stress. C2, C3, C4, and C5 exhibit higher strength reductions, with C2 showing the most significant reduction (53.33%) alongside a residual strength of only 33.33%. This suggests potential vulnerabilities in the structural integrity of these columns. Overall, the residual strength on Floor 4 is generally higher than the reduced strength on Floor 3, highlighting varying performance levels across the columns. The results emphasize the importance of assessing both strength reduction and residual capacity to ensure the safety and reliability of concrete structures subjected to fire. These findings underscore the need for further investigation into enhancing fire resistance in structural design, particularly for elements exhibiting substantial strength reductions.

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