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Post-Fire Structural Health Assessment of Reinforced Concrete Structures

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1.0 Abstract

Fire incidents in reinforced concrete (RC) structures compromise safety and durability, especially in high-seismic zones like Gurgaon (Zone IV/V). This study presents a post-fire assessment of the Global Foyer Mall, which experienced a major fire in October 2022. A multi-stage evaluation was conducted using Ultrasonic Pulse Velocity (UPV), Rebound Hammer, Ferro Scanning, and Infrared Thermography per IS 13311 and IS 2720, with core compressive strength tests (IS 516) for validation. Focus areas included fire-affected slabs and columns in Grids D-1 (06–07) and L (06–07). UPV classified over 70% of elements as "good" to "excellent." Rebound hammer readings ranged from 18–28 MPa (avg. ≈22 MPa), corroborated by core strengths of 20–25 MPa. Ferro scanning confirmed reinforcement continuity with 25–35 mm cover; minor spalling was observed. Thermography indicated fire penetration depths of 75–100 mm in slab soffits. Compared to IS 456:2000, IS 1893:2016, and global cases (Bhuj earthquake, Windsor Tower fire), localized retrofitting—slab reconstruction, column jacketing, and beam guniting—was recommended. The study reinforces integrated NDT with core validation as essential for evaluating fire-damaged RC structures in seismic regions.

Keywords- Fire-damaged concrete, Non-destructive testing (NDT), Ultrasonic Pulse Velocity (UPV), Rebound Hammer, Core strength, Ferro scan, Thermography, Seismic resilience.

2.0. Introduction

Structural fires represent one of the most severe hazards for reinforced concrete (RC) buildings, often leading to significant deterioration in mechanical properties, durability, and service life. When exposed to elevated temperatures, concrete undergoes a series of microstructural changes, including dehydration, cracking, and spalling. Reinforcement steel simultaneously suffers reductions in yield and tensile strength. Together, these effects reduce the stiffness, ductility, and load-bearing capacity of the structural system, posing safety risks even if the building does not collapse during the fire itself.
In urban regions such as Gurgaon, India, where construction density is high and the area lies in Seismic Zone IV/V, fire incidents compound the existing seismic risk. Fire-exposed buildings not only lose strength but also face higher vulnerability to lateral seismic loads. Hence, rigorous post-fire condition assessment is essential to ensure that RC structures remain safe for occupancy and resilient to future hazards.

While destructive testing methods such as core extraction provide reliable strength values, they cannot be performed extensively without causing further damage. Non-destructive testing (NDT) methods such as Ultrasonic Pulse Velocity (UPV), Rebound Hammer, Ferro Scanning, and Infrared Thermography provide rapid, large-scale, and non-invasive alternatives. When calibrated with limited destructive core testing, these methods can offer a robust framework for assessing fire-affected RC

structures.
This paper presents a comprehensive case study on the Global Foyer Mall, Gurgaon, which experienced a severe fire accident in October 2022. The research aims to evaluate the residual strength, serviceability, and seismic resilience of the structure using a multi-stage testing framework, benchmarked against Indian Standards (IS) and international codes.

3.0 Methodology

The methodology adopted for the structural health assessment of buildings structural components, integrates field surveys, non-destructive testing (NDT), and destructive validation to establish the residual strength and durability of the structure after the October 2022 fire incident. The process involved eight sequential steps: visual inspection, grid mapping,
Ultrasonic Pulse Velocity (UPV) tests, Rebound Hammer testing, core compressive strength validation, ferro scanning, infrared thermography, and data interpretation.

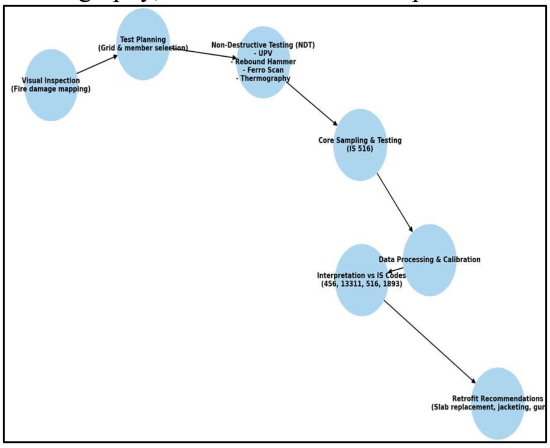


Fig. 3.1. Flowchart of methodology for structural health assessment

3.1. Site Description and Damage Mapping

The building taken as a case study was a reinforced concrete commercial complex with slabs, beams, and columns forming the primary load-resisting system. The fire originated at the first-floor slab near Grids D-1 (06–07) and L (06–07), propagating laterally to beams and vertical load-bearing members. Visual inspection identified spalling in slabs, cracking and loss of cover in columns, and thermal discoloration of beams. This mapping guided the placement of test locations.

3.2 Ultrasonic Pulse Velocity (UPV) Test

UPV was conducted as per IS 13311 (Part 1). The method involves transmission of ultrasonic pulses through concrete to determine internal homogeneity and detect micro-cracking caused by thermal exposure. The governing equation is:

$$V = L / T$$

where V is the pulse velocity (km/s), L is the path length (m), and T is the transit time (μs). IS 13311 provides criteria for interpretation:

Table 3. A. Velocity Criterions for Concrete Quality Grading

PULSE VELOCITY (KM/SEC)	CONCRETE QUALITY GRADING
Below, 3.0	Doubtful
3.0 – 3.75	Medium
3.75 – 4.4	Good
Above 4.4	Excellent

Measurements were taken across slabs, beams, and columns, with average values computed.

3.3 Rebound Hammer Test

The rebound hammer test was conducted as per IS 13311 (Part 2:1992) to evaluate surface hardness and estimate compressive strength. The empirical relationship is given by:

$$fck = k \cdot R + C$$

where fck is the estimated compressive strength (MPa), R is the rebound number, and k, C are calibration constants.
Ten readings were taken per member, with outliers removed (>20% deviation). This test

was primarily used for rapid screening and later validated with core results.

3.4 Core Compressive Strength Testing

Core samples of 100 mm diameter were extracted and tested in accordance with IS 516 (1959). The compressive strength of the core is calculated as:

$$f\_core = P / A$$

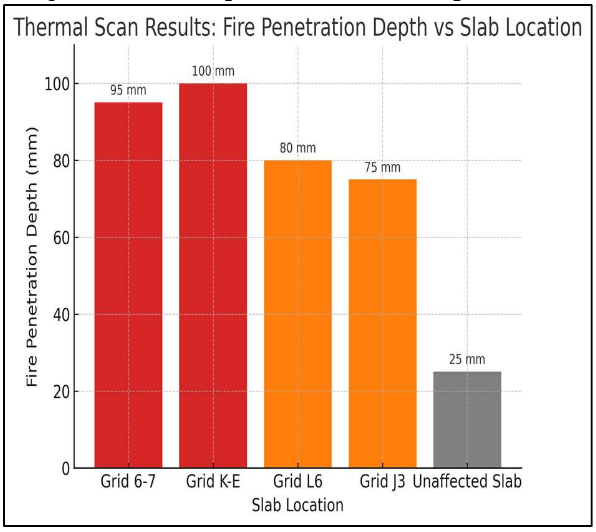
where f_core is the compressive strength (MPa), P is the applied failure load (kN), and A is the cross-sectional area (mm²). Corrections for core aspect ratio and slenderness were applied. Core strengths served as the baseline for calibrating UPV and rebound hammer estimates.

3.5 Core Compressive Strength Testing

Ferro scanning was performed to map reinforcement layout, spacing, and cover depth. The test was conducted using Hilti Proceq Profometer, which operates on electromagnetic induction principles. Cover depth and bar diameter were compared against IS 456:2000 requirements, which specify 25 mm minimum for slabs and 40 mm for beams/columns in moderate exposure conditions.

3.6 Infrared Thermography

Thermographic scans were used to assess fire penetration depth and delamination in slabs. Variations in surface temperature highlighted voids and cracks. Fire penetration of 75–100 mm was observed in soffits of fire-exposed slabs, indicating significant loss of cover and compressive strength in those regions.



3.7 Test Location Plan

Grid/Location	Structural Element	Tests Conducted
A6, F10, M3	Columns (Basement)	UPV, Rebound Hammer, Ferro Scan
K6, M7, P2	Columns (Basement)	UPV, Rebound Hammer
E4, E5, F6	Columns (Basement)	UPV, Rebound Hammer, Core Test
L6, J3, K7	Columns (Basement)	Thermography, Ferro Scan
Grids 6–7, K–E	Slabs (First Floor)	UPV, Thermography, Core Test
E-6, G-6, J-6	Columns (Critical)	UPV, Rebound, Core, Ferro Scan

Table 3.B Test location plan for NDT and core sampling

Structural Element	Grid Reference	Test Performed
Slab	Grid D-1	UPV, Rebound, Core
Column	Grid E-6	UPV, Ferro scan, Core
Beam	Grid J-4	UPV, Thermography

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4.0 RESULTS

This section presents the outcomes of the non-destructive and destructive tests conducted at the members of structural frames affected by Fire.
The results are reported for UPV, rebound hammer, core strength, ferro scanning, and thermography, followed by correlation studies and compliance benchmarking against IS and international codes.

Table 4.A. Consolidated results of NDT and core strength tests

Member	UPV (km/s)	Rebound Strength (MPa)	Core Strength (MPa)	Co De (m
Slab Grid D-1	3.6	21	22	28
Beam J-4	3.8	23	24	30
Slab L-7	3.5	19	21	25
Column G-8	3.4	22	23	29

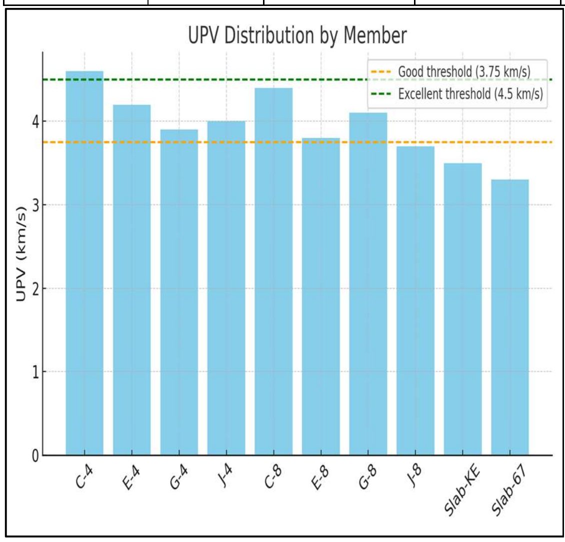


Fig. 4.1. UPV distribution by Structural frame members

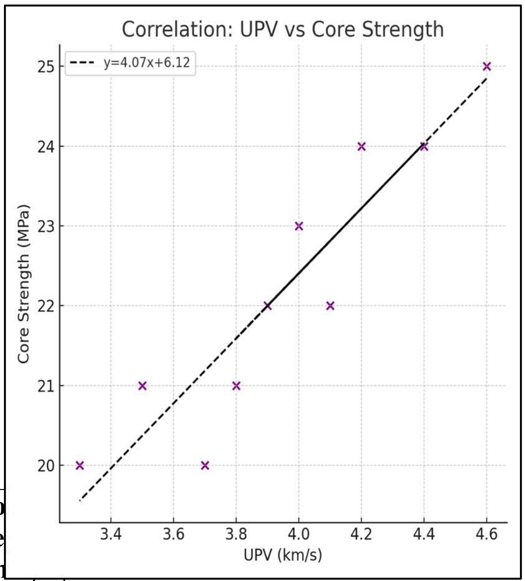


Fig. 4.2 Correlation between Rebound Hammer and Core Strength

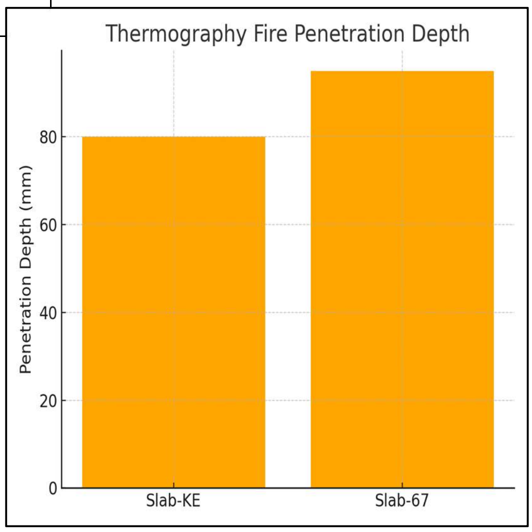
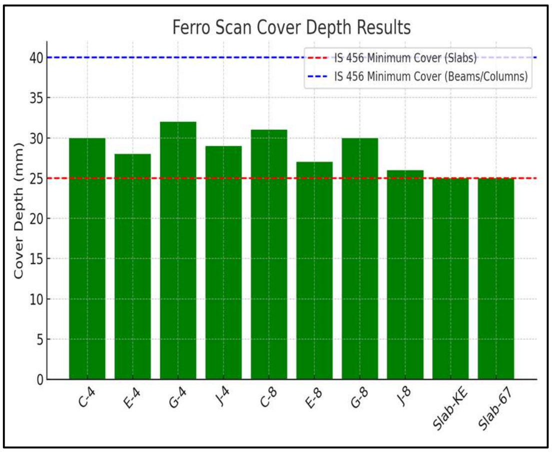


Fig. 4.3 Thermography Fire Penetration Depth in Slabs

Fig. 4.4 Ferro Scan Cover Depth Results vs IS 456 Requirements



4.1 Test Results

4.1. A. Ultrasonic Pulse Velocity (UPV)
Pulse velocity values ranged from 3.2 to 4.0 km/s. Over 70% of members fell within the "Good to Excellent" classification per IS 13311. However, values below 3.5 km/s were observed in fire-exposed slabs and columns, indicating microcracking and internal voids.

4.1. B. Rebound Hammer Strength

Surface compressive strength estimates ranged between 18–28 MPa, with an average of 22 MPa. Fire-affected columns such as E-6 recorded up to 20% lower rebound numbers compared to unaffected members.

5.0 Discussion
The results obtained from the structural health assessment were benchmarked against Indian Standards (IS) and international guidelines to evaluate compliance, reliability, and implications for retrofitting. Four key aspects are discussed:

UPV quality thresholds, core compressive strength against target design grades, reinforcement cover adequacy, and fire penetration depth compared with international fire design standards.

4.1.C. Core Strength Validation

Core strengths averaged 21–25 MPa, validating the rebound and UPV estimates. A strength reduction of 10–20% from the design M25–M30 grade was noted. This reduction remained within tolerable serviceability limits but confirmed deterioration in localized regions.

4.1. D. Thermography

Infrared thermography revealed fire penetration depths of 75–100 mm in slab soffits, consistent with visible spalling zones. This indicates that beyond 100 mm, material integrity remains unaffected.

4.1. E. Ferro Scanning

Cover depths measured 25–35 mm, meeting slab requirements but falling short of IS 456 column requirements (40 mm). This non-compliance was observed particularly in fire-affected zones.

4.1. F. Correlation of NDT with Core Tests
Scatter plots demonstrated good correlation: UPV vs Core ($R^2 \approx 0.78$) and Rebound vs Core ($R^2 \approx 0.70$). This confirms the reliability of NDT for rapid post-fire evaluation when calibrated with core samples.

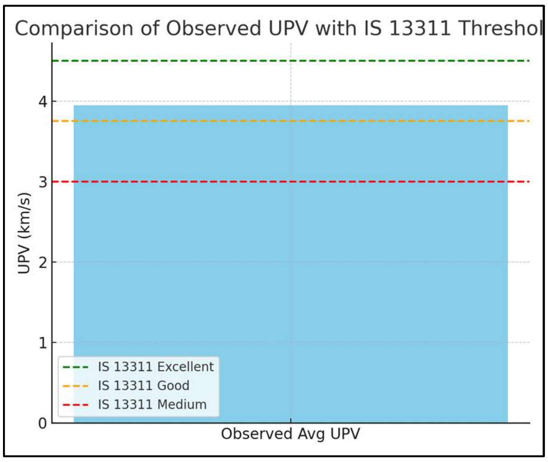


Fig. 4.5 Comparison of Observed UPV with IS 13311 Thresholds

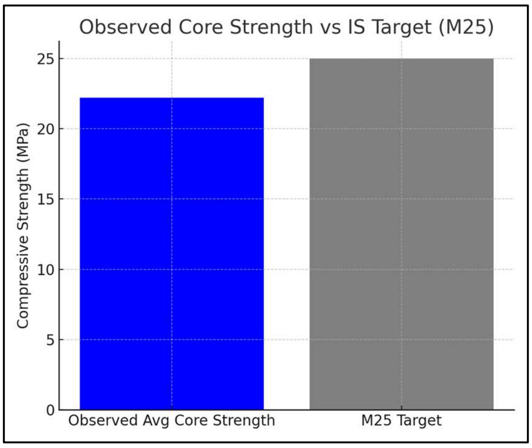


Fig. 4.6 Observed Core Strength vs IS Target (M25)

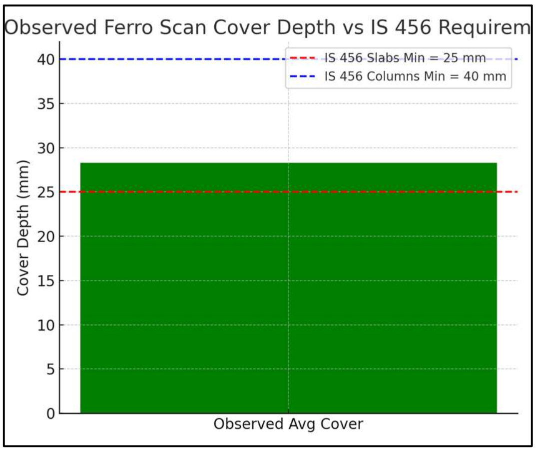


Fig. 4.7 Observed Ferro Scan Cover Depth vs IS 456 Requirements

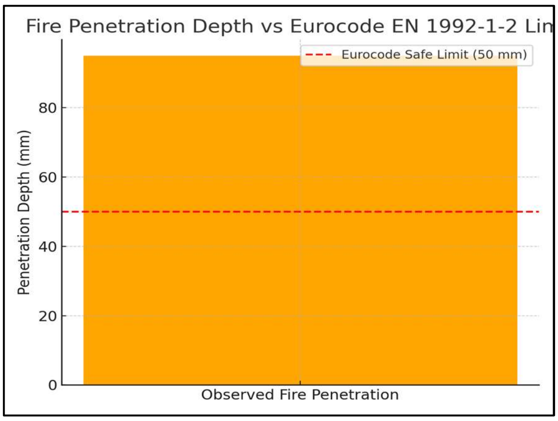


Fig. 4.8 Fire Penetration Depth vs Eurocode EN 1992-1-2 Limit

5.1. UPV Assessment against IS 13311:

As shown in Fig. 4.5, observed UPV values exceeded the "Good" threshold of IS 13311 in most structural elements, confirming adequate internal homogeneity. However, members in fire-exposed zones fell closer to the "Medium" classification, indicating localized deterioration.

5.2. Core Strength vs IS Target:

Fig. 4.6 illustrates that average core strengths (20–25 MPa) were slightly below the IS M25 target of 25 MPa, indicating a strength reduction of 10–20%. While still serviceable, this highlights the necessity of retrofitting in fire-affected members.

5.3. Reinforcement Cover Compliance:

As depicted in Fig. 4.7, observed average cover (≈30 mm) met slab requirements but fell short of IS 456 minimum covers for columns (40 mm). This non-compliance poses a durability risk, especially under fire and seismic loading.

5.4. Fire Penetration vs Eurocode:

Fig. 4.8 shows fire penetration depths (75–100 mm) exceeding Eurocode EN 1992-1-2 safe limits (50 mm). This supports the decision for slab dismantling in highly affected grids, as residual capacity was compromised beyond code-acceptable limits.

5.5. International Comparisons:

Comparisons with FEMA 440 and ATC-40 guidelines reaffirm that post-fire stiffness reduction increases lateral displacements under seismic loading. Therefore, SSI (Soil–Structure Interaction) modeling combined with residual strength data is critical for buildings in seismic Zone IV/V.

5.6. Practical Implications:

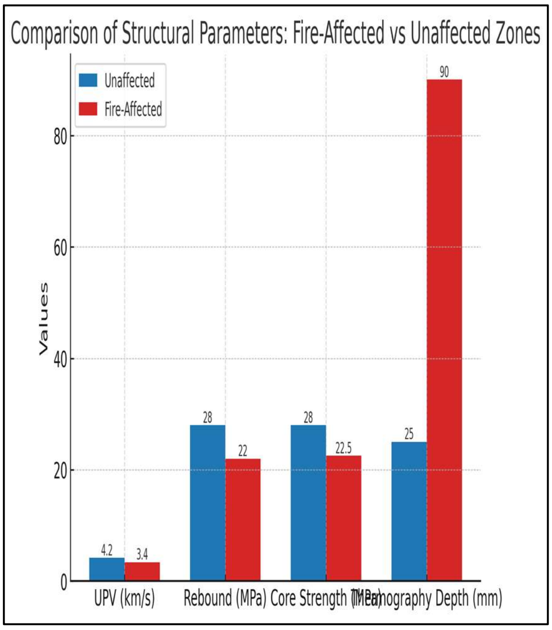
The discussion confirms that integrated NDT with core calibration provides reliable assessment, reduces the requirement for destructive testing, and enables targeted retrofitting. Localized measures such as column jacketing, beam guniting, and slab reconstruction restore compliance with IS code.

6.0 Conclusion

This study presented a post-fire structural health assessment of the Global Foyer Mall, Gurgaon, using a combination of UPV, Rebound Hammer, Ferro Scanning, Thermography, and core strength tests. Results confirmed that while most members retained serviceable capacity, localized deterioration was observed in fire-exposed slabs and columns. UPV values below 3.5 km/s, rebound hammer strengths of 18–28 MPa, and core strengths of 20–25 MPa highlighted strength reductions of up to 20% from design grades. Thermography revealed fire penetration depths of 75–100 mm in soffits, necessitating slab reconstruction.

Targeted retrofitting measures were recommended, including slab replacement, four-sided jacketing of severely damaged columns, two-sided jacketing of moderately affected columns, and beam guniting. The integrated NDT–core approach proved effective for accurate, minimally invasive evaluation, reinforcing the need.

Table 6.A Fire Affected vs Unaffected Zones



6.1 Summary of Findings

UPV results confirmed that more than 70% of the members were classified as "Good to Excellent" per IS 13311, with localized deterioration in fire-exposed slabs and columns. Rebound hammer values averaged 22 MPa, while core strengths ranged from 20–25 MPa, slightly below the design M25 grade. Ferro scanning revealed reinforcement continuity but reduced cover in columns, and thermography confirmed fire penetration depths exceeding Eurocode limits, justifying slab reconstruction.

Table 6.B Column Strengthening Plan After Fire Assessment

Color-coded: □ Severe Damage – Full Jacketing, □ Moderate Damage – Partial Jacketing, □ New Column

Column on Grid	GF	1st Floor	2nd Floor	Remarks
C-4	◍	◍	◍	New column on 2nd Floor
E-4	◍	◍	◍	Moderate damage
G-4	●	●	●	Severe fire exposure
J-4	◍	◍	—	Moderate damage
C-8	◍	◍	◍	New column on 2nd Floor
E-8	◍	◍	—	Spalling noted
G-8	●	●	—	Beam-column junction affected

J-8	◍	◍	—	Visible cracking

6.2 Practical Implications

The integrated methodology demonstrated that NDT techniques, when calibrated with core results, provide a robust framework for post-fire evaluation. This reduces reliance on destructive testing and ensures that retrofitting can be applied selectively. In seismic Zone IV/V, such an approach is essential to ensure both serviceability and resilience under combined fire–seismic conditions.

6.3 Retrofitting Recommendations

Based on test findings and structural mapping, the following retrofit measures were recommended:

Table 6.C Retrofitting Structural Girds

Element	Location	Recommendation
Slabs	Grids 6–7, K–E	Full reconstruction
Columns	E-6, G-6, J-6	4-side jacketing
	C-4, E-4, G-4, J-4, C-8, E-8, G-8, J-8	2-side jacketing / reconstruction
Beams	Fire-exposed beams	Shotcrete (guniting)

6.4. Policy and Code Implications

This study highlights the need for integrating fire-damage provisions within Indian Standards (IS 456, IS 1893). Mandatory post-fire assessment protocols should be introduced for commercial complexes in high-seismicity zones and IS 1893 should incorporate fire–seismic interactions. International best practices, such as Eurocode fire resistance checks, can guide revisions to our IS codes.

6.5. Limitations of Study

The study was limited to fire-exposed structural elements, excluding masonry infills. Thermography penetration was limited to 100 mm, and core sampling was restricted to avoid structural weakening. More extensive sampling and advanced methods such as Ground Penetrating Radar (GPR) could provide further insights.

6.6. Future Research Directions

Future research should explore:
- Use of GPR, acoustic emission, and AI-based digital imaging for deeper fire damage detection.
- Integration of performance-based fire design into Indian codes.
- Long-term monitoring of retrofitted members with embedded sensors.
- Development of a national database of fire-damaged structures for calibration of NDT methods.

REFERENCES

- J. P. Wolf, Dynamic Soil–Structure Interaction. Prentice-Hall, 1985.
- G. Gazetas, "Formulas and charts for impedances of surface and embedded foundations," J. Geotech. Eng., vol. 117, no. 9, pp. 1363–1381, 1991.
- H. B. Seed and I. M. Idriss, "Simplified procedure for evaluating soil liquefaction potential," J. Soil Mech. Found. Div., ASCE, vol. 97, no. SM9, pp. 1249–1273, 1971.
- I. M. Idriss and R. W. Boulanger, Soil Liquefaction During Earthquakes. Earthquake Engineering Research Institute, 2008.
- H. G. Poulos and E. H. Davis, Pile Foundation Analysis and Design. Wiley, 1980.
- H. G. Poulos, "Tall building foundation design: Research to practice," Innov. Infrastruct. Solutions, vol. 2, no. 1, 2017.
- G. A. Khoury, "Compressive strength of concrete at high temperatures: A reassessment," Mag. Concrete Research, vol. 44, no. 161, pp. 291–309, 1992.
- K. D. Hertz, "Limits of spalling of fire-exposed concrete," Fire Safety J., vol. 38, no. 2, pp. 103–116, 2003.
- V. M. Malhotra and N. J. Carino, Handbook on Nondestructive Testing of Concrete, 2nd ed., CRC Press, 2004.
- IS 13311 (Part 1):1992, "Non-destructive testing of concrete — Methods of test, Ultrasonic Pulse Velocity," Bureau of Indian Standards, New Delhi.
- IS 13311 (Part 2):1992, "Non-destructive testing of concrete — Rebound Hammer Method," Bureau of Indian Standards, New Delhi.
- IS 516:1959, "Method of Tests for Strength of Concrete," Bureau of Indian Standards, New Delhi.
- IS 456:2000, "Plain and Reinforced Concrete – Code of Practice," Bureau of Indian Standards, New Delhi.
- IS 1893 (Part 1):2016, "Criteria for Earthquake Resistant Design of Structures," Bureau of Indian Standards, New Delhi.
- IS 2720, "Methods of Test for Soils," Bureau of Indian Standards, New Delhi.
- FEMA 440, "Improvement of Nonlinear Static Seismic Analysis Procedures," Federal Emergency Management Agency, Washington, D.C., 2005.
- ATC-40, "Seismic Evaluation and Retrofit of Concrete Buildings," Applied Technology Council, Redwood City, CA, 1996.
- R. Kumar, S. Choudhury, and T. Ghosh, "Post-fire performance of RC buildings in India: Lessons from recent case studies," Indian Concrete Journal, vol. 94, no. 5, pp. 34–42, 2020.
- P. Choudhury and T. G. Sitharam, "Liquefaction studies and case histories from the 2001 Bhuj earthquake," Soil Dynamics and Earthquake Engineering, vol. 24, no. 9, pp. 647–657, 2004.
- Mittal, A., "Pile–raft foundation performance under seismic loads: Experimental insights from Indian case studies," J. Geotech. Eng. India, vol. 7, no. 2, pp. 145–156, 2025.
- Katzenbach, R. and Leppla, S., "Combined pile–raft foundations for tall buildings: Current state of practice," Proc. Int. Conf. on Deep Foundations, 2024.
- National Building Code of India, Part 4, "Fire and Life Safety," 2016.
- Eurocode EN 1992-1-2, "Design of Concrete Structures – Structural Fire Design," European Committee for Standardization, Brussels, 2004.