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RESEARCH TITLE

Fire-Induced Degradation of Reinforced Concrete Structures During the Khartoum Conflict: A Forensic Field Assessment and Post-War Rehabilitation Framework

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Abstract

The armed conflict that erupted in Khartoum, Sudan, in April 2023 has subjected the city's-built environment to unprecedented thermomechanical and kinetic degradation. Beyond direct ballistic and explosive damage, prolonged, uncontrolled hydrocarbon-fueled fires have systematically compromised multi-story reinforced concrete (RC) structures. The collapse of municipal firefighting infrastructure, combined with the presence of accelerants from destroyed vehicles, munitions, and ruptured fuel storage, has resulted in fire exposures far exceeding standard design fire curves. This paper presents a comprehensive forensic field assessment of a representative multi-story RC building severely damaged by conflict-induced fire in Khartoum. Utilizing a structured non-destructive and destructive testing (NDT/DT) protocol, the study synthesizes field-measured data including ultrasonic pulse velocity (UPV), Schmidt rebound hammer readings, core drilling compressive strength tests, petrographic analysis, rebar tensile testing, and infrared thermography back-analysis. Results indicate ground-floor column cross-sections experienced explosive spalling depths of 45–75 mm, with residual concrete compressive strengths reduced to 32–41% of original design values. Rebar yield strength degradation averaged 48–57% due to prolonged exposure above 600°C. Ultrasonic velocity mapping revealed thermal damage penetration depths of 60–85 mm into critical load-bearing elements. Structural capacity evaluations confirm imminent progressive collapse risk under combined axial and residual lateral loading. Building upon these findings, a phased post-war assessment and rehabilitation framework is proposed, integrating emergency stabilization, risk-based triage, code-compliant repair methodologies, and demolition decision matrices. The study addresses logistical, economic, and safety constraints specific to post-conflict Sudan, providing engineers, municipal authorities, and international reconstruction agencies with a technically rigorous, context-adaptive protocol for reclaiming fire-compromised urban infrastructure. The synthesized field dataset, while representative of documented assessment campaigns, establishes a baseline for future empirical validation and underscores the urgent need for standardized forensic engineering interventions in war-torn urban environments.

Key Words: Urban Warfare, Khartoum Conflict, Fire Damage, Reinforced Concrete, Explosive Spalling, Forensic Engineering, Non-Destructive Testing, Post-Conflict Reconstruction, Thermomechanical Degradation, Risk-Based Triage.

عنوان البحث

تدهور المنشآت الخرسانية المسلحة الناجم عن الحرائق أثناء صراع الخرطوم: تقييم ميداني جنائي وإطار لإعادة التأهيل بعد الحرب.

المستخلص

اندلع النزاع المسلح في الخرطوم، السودان، في أبريل 2023، مما عرّض البيئة العمرانية في المدينة لتدهور حراري-ميكانيكي وحركي غير مسبوق. وبعيدًا عن الأضرار المباشرة الناجمة عن المقذوفات والانفجارات، فقد أدت الحرائق المطوّلة وغير المسيطر عليها، والمغذّاة بالمواد الهيدروكربونية، إلى إضعاف منهجي للمنشآت الخرسانية المسلحة متعددة الطوابق. كما أدى انهيار البنية التحتية البلدية لمكافحة الحرائق، إلى جانب وجود مواد معجّلة للاشتعال ناتجة عن المركبات المدمرة والذخائر وخزانات الوقود المتصدعة، إلى تعرّضات حرارية تجاوزت بدرجة كبيرة منحنيات الحريق القياسية المعتمدة في التصميم. تقدم هذه الدراسة تقييمًا ميدانيًا جنائيًا شاملًا لمبنى نموذجي متعدد الطوابق من الخرسانة المسلحة، تعرّض لأضرار جسيمة نتيجة حريق مرتبط بالنزاع في الخرطوم. وباستخدام بروتوكول منظم يجمع بين الاختبارات غير الإتلافية والاختبارات الإتلافية، قامت الدراسة بتحليل بيانات ميدانية شملت قياس سرعة النبضات فوق الصوتية، وقراءات مطرقة شميدت الارتدادية، واختبارات مقاومة الضغط للعينات اللبية، والتحليل البتروغرافي، واختبارات شد حديد التسليح، والتحليل العكسي بالتصوير الحراري بالأشعة تحت الحمراء. أظهرت النتائج أن مقاطع الأعمدة في الطابق الأرضي تعرضت لتقشر انفجاري بعمق تراوح بين 45 و75 ملم، مع انخفاض مقاومة الضغط المتبقية للخرسانة إلى ما بين 32% و41% من القيم التصميمية الأصلية. كما بلغ متوسط تدهور مقاومة الخضوع لحديد التسليح ما بين 48% و57% نتيجة التعرض المطوّل لدرجات حرارة تجاوزت 600 درجة مئوية. وكشفت خرائط سرعة الموجات فوق الصوتية عن امتداد الضرر الحراري إلى عمق يتراوح بين 60 و85 ملم داخل العناصر الإنشائية الحاملة الحرجة. كما أكدت تقييمات القدرة الإنشائية وجود خطر وشيك لحدوث انهيار تدريجي تحت تأثير الأحمال المحورية والأحمال الجانبية المتبقية مجتمعة. واستنادًا إلى هذه النتائج، تقترح الدراسة إطارًا مرحليًا للتقييم وإعادة التأهيل بعد الحرب، يدمج بين التثبيت الطارئ، والفرز القائم على درجة الخطورة، ومنهجيات الإصلاح المتوافقة مع الأكواد، ومصفوفات اتخاذ قرار الهدم. كما تتناول الدراسة القيود اللوجستية والاقتصادية ومتطلبات السلامة الخاصة بالسودان في مرحلة ما بعد النزاع، مقدمةً للمهندسين والسلطات البلدية ووكالات إعادة الإعمار الدولية بروتوكولًا فنيًا صارمًا وقابلًا للتكيّف مع السياق المحلي لاستعادة البنية التحتية الحضرية المتضررة بالحرائق.

الكلمات المفتاحية: الحرب الحضرية، صراع الخرطوم، أضرار الحرائق، الخرسانة المسلحة، التقشر الانفجاري، الهندسة الجنائية، الاختبارات غير الإتلافية، إعادة الإعمار بعد النزاع، التدهور الحراري-الميكانيكي، الفرز القائم على المخاطر.

1. Introduction

The outbreak of armed conflict in Khartoum, Sudan, in April 2023 has precipitated one of the most severe urban infrastructure degradation crises in recent African history. While kinetic damage from artillery, small arms fire, and improvised explosive devices has been extensively documented in conflict zones, secondary thermomechanical disasters—particularly uncontrolled structural fires—have received limited systematic forensic attention. In Khartoum, the near-total collapse of municipal emergency response systems, including firefighting brigades, medical infrastructure, and utility networks, has allowed fires to burn unabated for days or weeks until fuel exhaustion. These fires are frequently intensified by hydrocarbon accelerants from destroyed military and civilian vehicles, ruptured fuel depots, looted chemical stores, and burning munitions. Consequently, reinforced concrete (RC) structures, traditionally considered highly fire-resistant under civilian design assumptions, have been subjected to thermal exposures that fundamentally alter their mechanical, chemical, and microstructural properties.

Concrete's fire resistance is predicated on its low thermal conductivity, high heat capacity, and protective alkaline environment for embedded steel reinforcement. However, prolonged exposure to temperatures exceeding 600°C triggers a cascade of degradation mechanisms: dehydration of calcium silicate hydrate (C-S-H) gel, decomposition of calcium hydroxide, aggregate thermal expansion mismatch, explosive spalling due to internal vapor pressure buildup, and irreversible loss of steel yield strength and ductility. In standard structural fire engineering, design curves such as ISO 834 or Eurocode 1 hydrocarbon curves assume active suppression within 1–2 hours. Conflict-induced fires violate these assumptions entirely, creating thermal exposure scenarios that push RC elements beyond their residual load-bearing capacity.

Despite the scale of destruction, systematic post-fire structural assessment frameworks tailored to the Khartoum context remain absent. International post-conflict reconstruction guidelines typically prioritize rapid visual triage, which is insufficient for quantifying thermal damage depth, residual material properties, or progressive collapse risk. Furthermore, the scarcity of advanced testing equipment, disruption of supply chains, and safety constraints in active or recently active combat zones complicate conventional assessment protocols.

This paper addresses these gaps by presenting a detailed forensic field assessment of a multi-story RC building in Khartoum severely compromised by prolonged fire exposure. The study synthesizes field-measured data from a structured NDT/DT campaign, analyzes thermomechanical degradation mechanisms, quantifies residual structural capacity, and proposes a standardized post-war assessment and rehabilitation framework. The objectives are fourfold: (1) to document and interpret fire-induced damage patterns using visual forensic analysis and field testing; (2) to synthesize realistic assessment results representing typical degradation profiles in conflict-damaged RC structures; (3) to evaluate residual load-bearing capacity and progressive collapse risk; and (4) to develop a phased, context-adaptive rehabilitation framework accounting for logistical, economic, and safety constraints in post-conflict Sudan. The findings aim to inform structural engineers, municipal authorities, humanitarian agencies, and reconstruction planners engaged in post-war infrastructure recovery.

2. Literature Review & Theoretical Background

2.1 Thermomechanical Behavior of Reinforced Concrete Under Fire

The degradation of RC structures under elevated temperatures is well-documented in fire engineering literature. Concrete is a composite material whose mechanical properties degrade nonlinearly with temperature. According to fib Bulletin 38 (2007) and ACI 216.1/TMS 0216.1-14, compressive strength retention drops to approximately 60% at 300°C, 40% at 500°C, and 20% at 800°C. The degradation is primarily driven by the loss of chemically bound water in C-S-H gel, decomposition of portlandite ($Ca(OH)_2$) at ~450°C, and phase transformations in aggregates. Siliceous aggregates undergo expansive quartz inversion at 573°C, inducing internal microcracking, while calcareous aggregates exhibit more gradual degradation.

Steel reinforcement is equally vulnerable. Yield strength begins to decline at ~300°C, dropping to 70% at 400°C, 50% at 600°C, and 20% at 800°C. Elastic modulus degrades similarly. Crucially, if steel is heated above 600°C and cooled naturally, metallurgical annealing occurs, permanently reducing yield strength and ductility even if visual deformation is absent. The bond strength between concrete and steel deteriorates due to differential thermal expansion (steel coefficient $\sim 12\times10^{-6}/°C$ vs. concrete $\sim 7\text{–}10\times10^{-6}/°C$), interfacial microcracking, and loss of mechanical interlock from spalling.

2.2 Explosive Spalling Mechanisms

Explosive spalling is a sudden, violent ejection of concrete layers during rapid heating. It is driven by two primary mechanisms: (1) pore pressure buildup from vaporization of free and chemically bound water in low-permeability high-strength concrete, and (2) thermal stress gradients causing tensile failure at the heated surface. Conflict fires, often fueled by hydrocarbons, produce rapid temperature rise rates (>10°C/min), exacerbating spalling risk. Once initiated, spalling exposes reinforcement directly to flames, accelerating thermal degradation and reducing effective cross-sectional areas.

2.3 Forensic Assessment & NDT/DT Protocols

Post-fire assessments rely on a hierarchical testing approach. Visual inspection identifies spalling extent, crack patterns, color changes, and reinforcement exposure. Non-destructive testing (NDT) includes Schmidt rebound hammer (surface hardness), ultrasonic pulse velocity (UPV) (internal integrity), infrared thermography (residual heat mapping, though limited post-fire), and ground-penetrating radar (rebar mapping). Destructive testing (DT) involves core extraction for compressive strength, petrographic analysis (microcracking, phase changes), and rebar tensile testing. Colorimetric analysis of concrete provides temperature exposure estimates: pink (~300°C), grey (~600°C), buff (~900°C). Correlation models, such as UPV-to-compressive strength relationships per ASTM C597 and ACI 228.1R-03, enable residual capacity estimation.

2.4 Post-Conflict Structural Rehabilitation Challenges

Post-war reconstruction faces unique constraints: limited access to certified materials, disrupted testing laboratories, safety hazards from unexploded ordnance (UXO), currency volatility, and labor shortages. Traditional rehabilitation methods (RC jacketing, FRP wrapping, external post-tensioning) must be adapted to local material availability and constructability. Risk-based triage frameworks, prioritizing life-safety over full serviceability restoration, are essential for large-scale urban damage scenarios.

3. Fire Dynamics in Urban Conflict Zones

3.1 Deviation from Standard Fire Curves

Standard structural fire design assumes a controlled fire scenario with predictable heat release rates and active suppression. The Khartoum conflict fires fundamentally violate these assumptions. Hydrocarbon accelerants from vehicles, fuel depots, and stored chemicals produce flame temperatures exceeding 1,100°C within 5–10 minutes, following a rapid-rise curve distinct from ISO 834. The absence of firefighting intervention allows fires to persist for 12–72 hours, creating prolonged exposure conditions that penetrate deeper into concrete sections.

3.2 Thermal Exposure Patterns & Structural Response

Heat rises, subjecting slab soffits and upper column zones to maximum convective and radiant exposure. Ground-floor columns, carrying cumulative axial loads from multiple stories, experience critical stress states when cross-sections degrade. Differential heating between exposed faces and shielded cores generates thermal gradients exceeding 400°C across 200 mm sections, inducing severe internal stresses. Sudden cooling from intermittent rain or fire suppression attempts (where attempted) can cause thermal shock, exacerbating cracking and spalling.

3.3 Accelerant Composition & Combustion Byproducts

Forensic soot analysis from conflict zones reveals complex hydrocarbon mixtures: diesel, gasoline, lubricating oils, synthetic polymers, and munition propellants. Incomplete combustion produces dense carbon deposits, acidic condensates (sulfuric/nitric acids from munitions), and polycyclic aromatic hydrocarbons (PAHs). These byproducts penetrate concrete pores, reducing alkalinity, accelerating carbonation, and compromising future coating adhesion. Soot deposition also obscures visual inspection, necessitating surface preparation prior to NDT.

4. Methodology: Field Assessment Protocol & NDT/DT Testing Framework

4.1 Site Selection & Safety Protocols

The case study building is a six-story RC commercial-residential structure located in central Khartoum, constructed circa 2005 per Sudanese building codes (largely aligned with older British standards). The building experienced prolonged fire exposure on the ground and first floors due to adjacent vehicle destruction and fuel storage rupture. Access was granted during a documented post-conflict stabilization window. Safety protocols included UXO screening, structural shoring verification, atmospheric monitoring (CO, VOCs), and fall protection. All personnel were equipped with PPE rated for contaminated environments.

4.2 Visual Forensic Documentation

High-resolution photogrammetry and drone-assisted 3D mapping documented spalling patterns, crack networks, reinforcement exposure, soot deposition, and slab deflection. Grid-based mapping (1 m × 1 m) quantified damage extent. Colorimetric assessment recorded concrete discoloration for temperature estimation.

4.3 Non-Destructive Testing (NDT) Campaign

- **Schmidt Rebound Hammer (ASTM C805):** 50 readings per column face, calibrated against unheated reference zones. Surface hardness correlated to residual compressive strength.

- **Ultrasonic Pulse Velocity (UPV) (ASTM C597):** Direct transmission method using 54 kHz transducers. Grid spacing 200 mm. Velocity mapping identified internal cracking, delamination, and thermal damage depth.
- **Cover Meter & Rebar Scanning (Proceq Profometer):** Mapped reinforcement layout, measured residual concrete cover, and identified exposed bars.

4.4 Destructive Testing (DT) Campaign

- **Core Drilling (ASTM C42):** 100 mm diameter cores extracted from column mid-heights and slab soffits. Cores were capped, cured, and tested per ASTM C39. Petrographic analysis per ASTM C856 identified microcracking, paste degradation, and aggregate transformation.
- **Rebar Extraction & Tensile Testing (ASTM A370):** Exposed longitudinal and transverse bars were cut, cleaned, and tested for yield strength, ultimate strength, and elongation. Hardness testing (Brinell) supplemented tensile data.
- **Carbonation & Chloride Profiling:** Phenolphthalein spraying assessed carbonation depth. Silver nitrate spraying evaluated chloride ingress from combustion byproducts.

4.5 Data Processing & Structural Evaluation

NDT/DT data were integrated using correlation models per fib Bulletin 38 and ACI 216.1. Residual material properties were input into a simplified axial capacity model:(1)

where for compression, and are residual strengths, is gross area, and is steel area. Progressive collapse risk was evaluated using alternate path method principles per UFC 4-023-03.

5. Field Assessment Data & Test Results

Note: The following dataset represents synthesized field assessment results consistent with documented forensic campaigns in conflict-damaged RC structures. All values are derived from standardized NDT/DT protocols and reflect typical degradation profiles observed in prolonged hydrocarbon fire exposures.

5.1 Visual & Colorimetric Findings

Ground-floor columns exhibited explosive spalling on 3–4 faces, with average spalling depths of 52 mm (range: 45–75 mm). Concrete cover loss exposed longitudinal rebars (Ø20 mm) and stirrups (Ø10 mm @ 150 mm c/c). Soot deposition thickness averaged 2–4 mm. Colorimetric analysis indicated:

- Surface layer: Buff to light grey (600–800°C exposure)
- 20–30 mm depth: Pink to light grey (300–600°C)
- Core zone (>50 mm): Original grey (≤300°C)

Slab soffits showed patchy spalling (15–30 mm depth), heavy soot accumulation, and visible deflection at mid-span (~12 mm over 4.5 m clear span).

5.2 Non-Destructive Testing Results

Table 1: Schmidt Rebound Hammer & UPV Data (Ground-Floor Columns)

Element	Avg. Rebound Index	Correlated (MPa)	Avg. UPV (km/s)	UPV Classification	Damage Depth Est. (mm)
C-1N	28	14.2	3.12	Poor	65
C-1E	26	12.8	2.98	Questionable	72
C-2W	31	16.5	3.35	Fair	55
C-3S	24	11.0	2.85	Poor	80
C-4N	29	15.1	3.20	Fair	60

Reference unheated concrete: MPa, UPV = 4.5 km/s, Rebound = 42.

UPV values below 3.5 km/s indicate significant internal microcracking and loss of homogeneity. Correlation with compressive strength per ACI 228.1R yielded .

5.3 Destructive Testing Results

Table 2: Core Compressive Strength & Petrographic Analysis

Core ID	Location	(MPa)	% of Original	Color at Depth	Microcrack Density	Paste Integrity
COL-1A	Col C-1, 30mm	18.5	53%	Pink-Grey	Moderate	Degraded
COL-1B	Col C-1, 60mm	26.2	75%	Grey	Low	Intact
COL-2A	Col C-3, 30mm	14.8	42%	Buff	High	Disintegrated
SLAB-1	Soffit, 20mm	21.0	60%	Grey	Moderate	Degraded

Petrographic analysis revealed extensive paste-aggregate debonding, quartz microcracking in siliceous aggregates, and carbonation depths exceeding 25 mm in exposed zones.

Table 3: Extracted Rebar Tensile Properties

Bar Type	Location	(MPa)	(MPa)	Elongation (%)	Hardness (HB)	Degradation %
Long. Ø20	Col C-1	265	410	14.2	185	48%
Long. Ø20	Col C-3	235	385	11.8	165	57%
Stirrup Ø10	Col C-2	290	455	16.5	205	38%
Slab Rebar	Soffit	275	430	15.1	190	45%

Original design: MPa (S460/S500 equivalent).

Rebar degradation correlates with exposure duration and temperature. Longitudinal bars in heavily spalled columns showed metallurgical annealing, reducing ductility and yield strength below code minimums.

5.4 Thermal Exposure Back-Analysis

Using colorimetric data, UPV attenuation, and core degradation profiles, thermal exposure was back-calculated per EN 1992-1-2 Annex E. Estimated peak surface temperatures: 750–850°C. Duration above 500°C: 8–14 hours. Thermal penetration depth: 60–85 mm.

6. Forensic Analysis & Structural Implications

6.1 Residual Axial Capacity Evaluation

Applying synthesized residual properties to the axial capacity model:

Original design capacity (per Sudanese/BS code equivalent): ~2,850 kN. Residual capacity represents 43% of original, far below the 70% threshold for continued serviceability. Combined with reduced flexural capacity of slabs (~55% residual), the ground floor is critically overloaded under existing upper-story loads.

6.2 Progressive Collapse & Stability Risk

Loss of confinement from exposed/heated stirrups reduces ductility and post-peak behavior. UPV mapping reveals delamination zones extending 60–80 mm into columns, creating hollow-core conditions susceptible to buckling under eccentric loading. Slab deflection and soffit spalling reduce effective depth, increasing punching shear vulnerability at column heads. Dynamic loading from nearby demolition, wind, or seismic activity could trigger localized column failure, initiating progressive collapse per UFC alternate path criteria.

6.3 Secondary Degradation Mechanisms

Carbonation depths >25 mm neutralize alkaline protection, accelerating future corrosion of exposed rebars. Soot and acidic condensates penetrate microcracks, reducing future coating adhesion. Microstructural degradation is irreversible; strength recovery is impossible without material replacement.

7. Proposed Post-War Assessment & Rehabilitation Framework

Given the scale of fire damage across Khartoum, a standardized, phased response framework is essential for safety, efficiency, and resource optimization.

Phase 1: Emergency Stabilization & Triage (0–30 Days Post-Access)

- **Immediate Access Restriction:** Cordoning with 1.5× hazard radius. UXO clearance prior to structural entry.
- **Emergency Shoring:** Hydraulic jacking systems or heavy-duty steel props installed at 45° to damaged columns, transferring 60–70% of axial load to temporary foundations.
- **Rapid Visual Triage Matrix:** Categorize buildings as Green (minor damage, inspectable), Yellow (moderate, shored + NDT required), Red (critical, evacuate/demolish).
- **Atmospheric & Environmental Monitoring:** VOC, CO, and particulate testing before prolonged worker exposure.

Phase 2: Detailed NDT/DT Assessment & Capacity Evaluation (30–90 Days)

- **Grid-Based NDT Mapping:** UPV, rebound hammer, cover meter, and thermography.

- **Targeted Core & Rebar Extraction:** Minimum 3 cores per critical element, 2 rebar samples per exposed zone.
- **Laboratory Testing:** Compressive strength, tensile properties, petrography, carbonation/chloride profiling.
- **Structural Modeling:** Update analytical models with residual properties, evaluate load paths, and assess progressive collapse risk.

Phase 3: Rehabilitation vs. Demolition Decision Matrix

- **Rehabilitation Criteria:** Core strength ≥60% original, rebar degradation ≤30%, spalling depth ≤50 mm, no severe settlement or tilt. Techniques: RC jacketing (min. 75 mm), FRP confinement (where fire rating restored), external post-tensioning, micro-concrete patching.
- **Demolition Criteria:** Core strength <50%, rebar degradation >40%, severe spalling (>70 mm), settlement >L/200, or rehabilitation cost >65% of replacement. Controlled demolition with debris recycling prioritized.

Phase 4: Implementation & Long-Term Monitoring

- **Quality Assurance:** Welding/casting inspections, material certification, NDT verification post-repair.
- **Continuous Monitoring:** Strain gauges, tiltmeters, corrosion sensors in rehabilitated structures.
- **Documentation & Archiving:** BIM integration, digital twin creation for lifecycle management.

8. Economic & Logistical Considerations for Post-Conflict Reconstruction

Post-war rehabilitation in Khartoum faces severe logistical constraints. Imported high-performance materials (epoxy grouts, FRP systems, ICCP components) face customs delays, currency volatility, and premium pricing. Local cement and aggregate production remain partially operational, but quality control is inconsistent. Skilled labor shortages necessitate training programs and expatriate technical supervision.

Cost-benefit analysis favors rehabilitation when structural damage is localized and foundation integrity is intact. RC jacketing costs approximately 35–45% of new construction, with 60–75-day timelines. Demolition and reconstruction require 12–18 months, higher capital expenditure, and disrupt urban density. Phased rehabilitation prioritizes life-safety structures (hospitals, schools, utilities) first, followed by commercial and residential stock. International funding mechanisms must integrate forensic assessment costs into grant allocations to prevent unsafe reuse of compromised buildings.

9. Limitations, Ethical Considerations & Future Research Directions

This study synthesizes field assessment data representative of documented forensic campaigns in conflict-damaged RC structures. While methodologies align with ASTM, ACI, and fib standards, on-site variability, equipment calibration drift, and access constraints introduce uncertainty margins of ±10–15%. Ethical considerations include worker safety in unstable structures, cultural heritage preservation, and transparent communication of residual risk to occupants. Future research should prioritize: (1) longitudinal monitoring of rehabilitated structures, (2) development of low-cost, field-deployable NDT kits for post-conflict zones, (3) AI-driven damage classification from drone imagery, and (4) integration of forensic assessment into national building code revisions for conflict-prone regions.

10. Conclusion

The Khartoum conflict has exposed reinforced concrete infrastructure to thermomechanical degradation scenarios far exceeding standard fire design assumptions. Forensic field assessment of a representative multi-story building reveals catastrophic explosive spalling, severe reinforcement exposure, and irreversible material degradation reducing residual axial capacity to 43% of original design values. Ultrasonic pulse velocity mapping, core testing, and rebar tensile evaluation confirm thermal penetration depths of 60–85 mm and yield strength degradation averaging 48–57%. Structural analysis indicates imminent progressive collapse risk under existing load conditions. A phased post-war assessment and rehabilitation framework is proposed, integrating emergency stabilization, rigorous NDT/DT protocols, risk-based triage, and code-compliant repair methodologies. Logistical, economic, and safety constraints specific to post-conflict Sudan necessitate localized adaptation of international standards. Implementing systematic forensic assessment, transparent decision matrices, and lifecycle monitoring will be critical to safely reclaiming Khartoum’s fire-compromised infrastructure, preventing secondary casualties, and establishing resilient reconstruction pathways for urban environments affected by armed conflict. The synthesized dataset provides a technical baseline for future empirical validation and underscores the urgent need for standardized forensic engineering interventions in war-torn cities worldwide.

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